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Uranium Mining and Milling. The Need, the Processes, the Impacts, the Choices Administrator's Guide

Western Interstate Energy Board, Denver, CO

Prepared for

Environmental Protection Agency, Denver CO Region VIII

May 78

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URANIUM MINING & MILLING

THE NEED, THE PROCESSES, THE IMPACTS, THE CHOICES

ADMINISTRATOR'S GUIDE

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY

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16. ABSTRACT

The primary objective of the Guide is to address the technical, economic, social, and environmental factors that influence uranium mining and the siting of milling facilities in the western United States. Although the Guide is not a regulatory document, the information should be useful to local, state, and federal administrators, legislators, policy makers, planners, and regulators involved in the review or approval process for uranium projects. The information should also be of interest to citizens who would be affected by a proposed project.

The Guide also highlights information that is considered by industry during the planning process. For example, site-specific aspects of mill tailings management are receiving increased attention from regulators and industry, and some earlier tailings disposal practices are no longer acceptable.

A secondary objective of the Guide is to inform developers of the various options that may be available when planning uranium development projects. Although the location of the mine is fixed, there are options available in the design of the mill, such as alternative sites, process methods, waste disposal locations and pollution control techniques.

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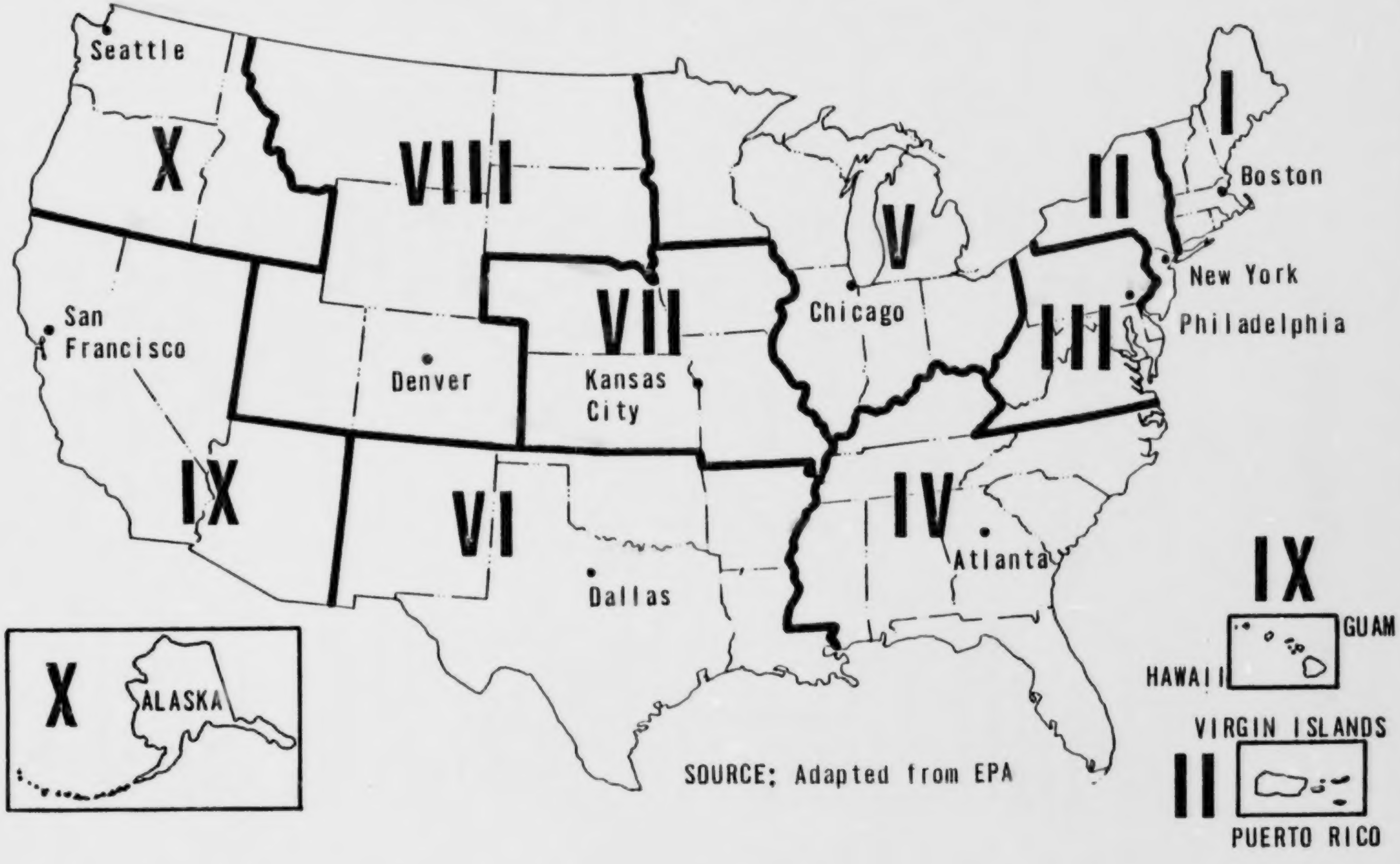
The work began under the direction of Mr. Wyatt Rogers, Jr., former Executive Director of WIEB/WINB, continued with the assistance of Mr. Fred Gross, and was completed under the direction of Mr. John Watson, the current WIEB/WINB Executive Director.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CHAPTER 1

Introduction

1.1
Purpose of the Guide

During the past decade, there has been increased concern about the environmental impacts of uranium mining and milling. In response to these concerns, improved methods have been developed to reduce or mitigate undesirable impacts. The Administrator's Guide is intended to meet the need for a single document that provides current information about these concerns and developments, particularly with respect to siting and operating uranium facilities. It focuses on those factors that require adoption of methods to prevent contamination of the environment, limit exposure to radioactivity, and mitigate long-term and short-term adverse effects, including socioeconomic impacts.

The primary objective of the Guide is to address the technical, economic, social, and environmental factors that influence uranium mining and the siting of milling facilities in the western United States. Although the Guide is not a regulatory document, the information should be useful to local, state, and federal adminstrators, legislators, policy makers, planners, and regulators involved in the review or approval process for uranium projects. The information should also be of interest to citizens who would be affected by a proposed project.

The Guide also highlights information that is considered by industry during the planning process. For example, site-specific aspects of mill tailings management are receiving increased attention from regulators and industry, and some earlier tailings disposal practices are no longer acceptable. To assure that the Guide will be useful to the uranium industry, comments from the Project Steering Committee (which includes mine and mill operators) were considered.

A secondary objective of the Guide is to inform developers of the various options that may be available when planning uranium development projects. Although the location of the mine is fixed, there are options available in the design of the mill, such as alternative sites, process methods, waste disposal locations and pollution control techniques.

1.2
Organization and Content

The Guide covers three important aspects of uranium resource development:

- Why and where uranium resource development is likely to occur
- How ore is mined and processed
- How environmental and social considerations relate to siting, licensing and operating new or expanded facilities

The focus of the Guide is on the third aspect listed. Accordingly, uranium resource development and mining and milling technology are treated to the level required to establish a basis for the more detailed discussions of siting and environmental impacts and socioeconomic considerations which follow. Each chapter is independent of the others so that the reader may go directly to the material of interest and not have to refer to sections in other chapters. The information in the Guide is basically limited to uranium mining and milling, the initial steps in the nuclear fuel cycle. A description of the fuel cycle and a simplified diagram of the activities necessary to fuel a nuclear power reactor and dispose of the wastes produced are presented in the Glossary.

The material is organized as follows:

Chapter 2-	"NUCLEAR POWER AND URANIUM RESOURCES." This chapter summarizes information prepared by the Department of Energy (DOE). The need for uranium for existing and future nuclear generating stations is discussed. Estimates of the uranium industry's production capability and data for known ore reserves and potential uranium resources are included. Additionally, areas with favorable uranium geology that may be the site of new or increased activity are shown.
Chapter 3-	"MINING AND MILLING URANIUM ORE." A generalized perspective of uranium mining and milling technology is presented. Project lead times and relative costs are compared for a conventional mine and mill complex and an in-situ (solution mining) operation. Engineering techniques for mill tailings management are included.

ORGANIZATION, Continued

Chapter 4- "SITING AND ENVIRONMENTAL IMPACT." Those factors affecting uranium mines and the site specific conditions which influence location of mills are described. The biological, chemical, and radiological impacts that occur during development, operation, and post-reclamation are discussed.

Chapter 5- "SOCIOECONOMIC CONSIDERATIONS." The social and economic costs and benefits associated with uranium resource development are reviewed and summarized. The positive and negative impacts of development on employment, income, and population are discussed. Jurisdictional problems, competition for labor and land, and the stress on public services and finance are analyzed. The opportunity and timing of mitigation and growth management strategies are reviewed. Selected data from New Mexico, Wyoming, and Utah are presented to illustrate growth-induced impacts and mitigation practices in regions experiencing rapid development.

1.3
Uranium Mill Licensing

The Guide refers to many of the licensing and regulatory requirements that apply primarily to uranium mines and mills. The licensing process is complex, and specific requirements for a uranium project vary from state to state. Timely coordination with regulatory authorities and an understanding of their requirements are essential to project scheduling and planning. Such coordination must include federal, state and county officials.

One major distinction in licensing uranium mills (and any other facility where ore is processed) is in the role of the Nuclear Regulatory Commission (NRC) and the states. The provisions of the Atomic Energy Act of 1954, as amended, provide for states to enter into agreement with the NRC and perform as the regulatory authority. Those states which have been delegated licensing authority are called "agreement" states. Those states in which the NRC maintains its authority are called "non-agreement" states. The information on this subject and a list of pertinent regulations and guidelines are included in Section 4.1 of Chapter 4.

1.4
Comments and Updating

The information in the Guide was compiled from many sources. It has been carefully reviewed by representatives of government and industry to eliminate errors or inconsistencies and to update information obtained from the literature when appropriate. Readers are invited to submit comments to:

U. S. Environmental Protection Agency
Region VIII
1860 Lincoln Street
Denver, CO 80295
Attention Mr. Paul B. Smith

In the future, significant progress is expected to improve waste disposal practices and impact mitigation techniques for siting, design and construction of new uranium mines and mills. The Guide is in looseleaf form so that its usefulness may be extended by future revisions to reflect the results of this progress.

CHAPTER 2

Nuclear Power and Uranium Resources

2.1
The Need for Uranium

The need for uranium in the future will be determined by the contribution of nuclear power to the domestic and world energy supply. The generating capacity of new nuclear power plants is the subject of continuing study, and differing energy supply and demand scenarios have been projected. Increased exploration activity and mine and mill expansion and/or development clearly indicate that the domestic and international uranium industry is expecting significant growth in electric generation capacity from nuclear reactors. A recent study maintains that "the reactors now under construction will result in an increase in demand for fuel in excess of existing supply" and that "the fuel supply industry... must increase capacity in a major way during the next 10–20 years under the most pessimistic future nuclear plant order assumptions" (Nucleonics Week, March 16, 1978).

2.1.1
Projected Generation by Energy Sources

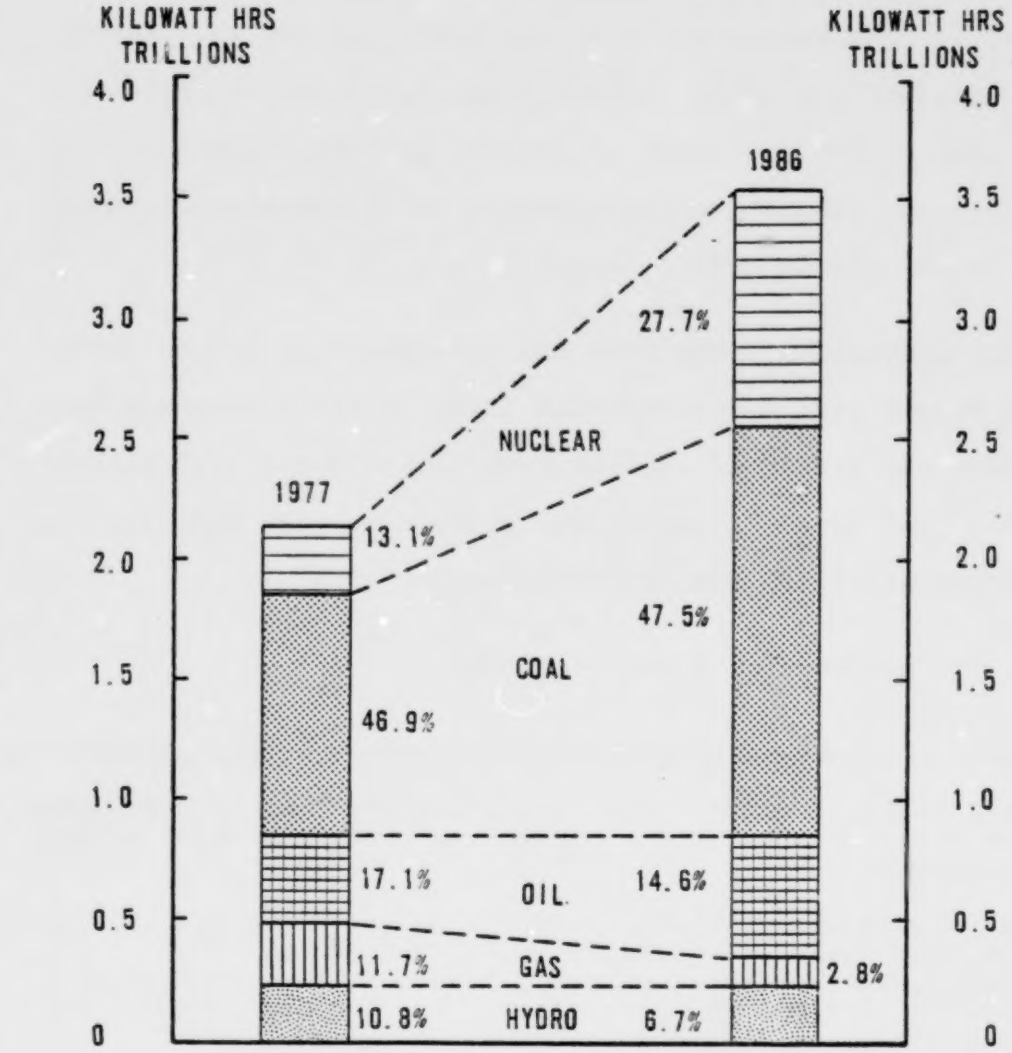
The National Electric Reliability Council (NERC) has projected the amount of electric power that will be generated from principal energy sources from 1977 through 1986, as shown on Table 2-1 below and in Figure 2-1. The NERC projections are especially useful in that they are revised annually to reflect utility-industry plans. The 1977 forecasts indicate a compound annual growth rate of 5.7 percent for the next ten years. The National Energy Plan (NEP) projects a similar rate of total energy consumption for industrial use at more than 5 percent a year through 1985 (NERC, July 1977).

Table 2-1

Projected Generation of Electric Power from Principal Energy Sources

	Net Electrical Energy Generated (Million KWHR)		Total Change
	1977	1986	1977 to 1986
Nuclear	281,211	989,000	+352%
Coal	1,009,851	1,698,164	+168%
Oil	350,189	458,163	+131%
Gas	238,240	93,751	- 61%
Hydro	232,915	238,256	+ 2%
Total	2,112,406	3,477,344	+164%

Source: NERC, August 1977.



SOURCE: NERC, August 1977.

* Other energy sources include diesel, geothermal and undesignated. These sources account for 0.4% in 1977 and 0.7% in 1986.

Figure 2-1
Electric Generation by Principal Energy Sources in Contiguous United States.

In 1976 nuclear power represented 8 percent of the installed generating capacity in the U.S. and accounted for 9.7 percent of electricity produced. NERC's projected increase from about 13 percent in 1977 to about 28 percent in 1986 represents an increase in nuclear energy production of three and one-half times in one decade (NERC, August 1977).

Nuclear generation data from the Department of Energy (DOE), Energy Information Administration (EIA), differs slightly from NERC data but show that nuclear power contributed 11.7 percent in 1977 to total electricity generation as compared to 9.4 percent in 1976 (DOE, EIA, February 1978).

Other NERC projections are as follows:

- Coal fired generation will nearly double from 1977 to 1986 and will average about 47 percent of electric energy production.
- Oil fired generation will continue at 17 percent through 1982 and decrease to less than 15 percent in 1986. Oil consumption will increase, however, from 631 million barrels in 1977 to 878 million barrels in 1986. Oil consumption will rise as it replaces natural gas.
- Gas fired generation will decline from 2.6 billion thousand cubic feet (MCF) to 1.1 billion MCF.
- Hydro generation will increase slightly but decrease in percentage to about 7 percent by 1986.

Most of the requirements for fuel for new base load capacity to be added by 1986 have been determined.

2.1.2
Growth of Nuclear Power

Nuclear electric power is expected to resume its growth and to significantly increase its share of the U.S. energy supply despite current institutional and regulatory constraints. Light water reactors (LWR's) will probably supply most of the nuclear generation capacity in the short term and during the early years of the twenty-first century.

Although forecasts for future growth of the nuclear power differ, most agree on continued growth in the industry. The National Energy Plan (NEP) proposed by the Administration in April 1977 projects U.S. installed nuclear capacity as follows:

Year	Nuclear Capacity MW(e)
1976	42,000
1985	127,000
1990	195,000
2000	380,000

According to the NEP, the nuclear power capacity will increase at the rate of 16 percent per year through 1985 and 7.3 percent from 1985 through 2000. An industry survey of reactor commitments shows reactor generation capacity of 159,964 MW(e) in 1985 and 193,591 MW(e) in 1990 (Electrical World, January 15, 1978). If these commitments by industry are realized, the NEP projection will be exceeded by about 33,000 MW(e) in 1985 and within 1,400 MW(e) of that projected for 1990.

2.1.3
Uranium Requirements

The total requirement for uranium through the year 2000 and for 30 more years thereafter is nearly 3 million tons U_3O_8. The uranium requirements for the 380,000 MW(e) projected in the year 2000 would be a little more than 1 million tons, using the present light-water reactors without reprocessing spent fuel. The 30-year lifetime requirements for this 380,000 MW(e) would be on the order of 2 million tons (U.S. DOE, December 1977). About 5000 to 8000 tons of uranium (U_3O_8) is required to fuel a 1000 MW(e) light-water reactor during its operating life (Boyd, 1977).

Uranium Production Capability

The DOE has estimated both the uranium industry's production capability and production capability versus requirements. In making these estimates, the DOE differentiates between ore reserves and potential resources. It also defines three categories of potential resources: "probable," "possible," and "speculative." These terms, as well as the basis of the costs, are defined in the Glossary.

The estimated capability of the uranium industry is based on the maximum annual tonnages that could be produced from $30/lb uranium reserves through the year 2000, as seen on Figure 2-2. Industry production and planned capacity is within the limits of reserves to about 1984; after that, production may be from probable potential resources (Nininger, 1978).

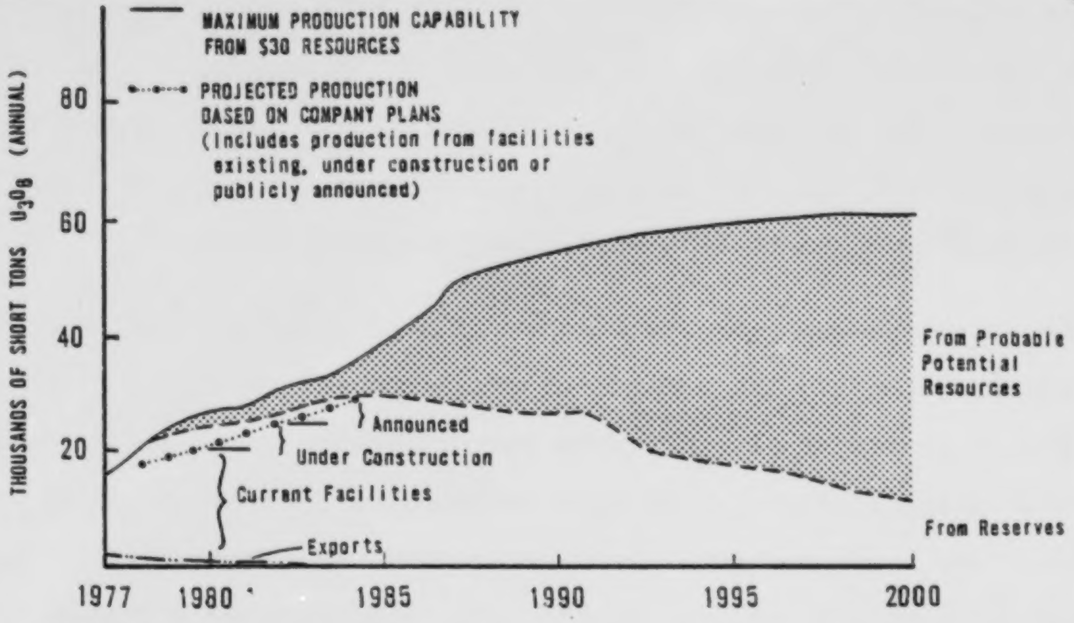


Figure 2-2
U.S. Uranium Production Capability

SOURCE: Nininger, 1978

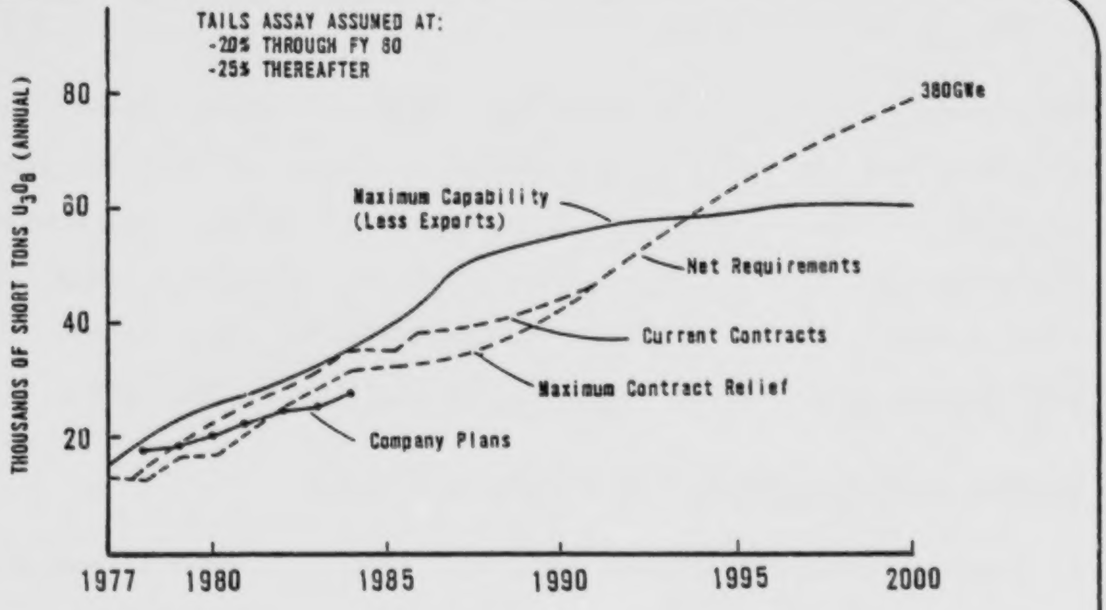


Figure 2-3
U.S. Uranium Production Capability vs. Requirements

The estimated uranium production capability versus requirements in the U.S. to the year 2000 are shown on Figure 2-3. In this figure, the maximum production capability (less exports) is compared with the net uranium requirements, based on uranium enrichment contracts with utilities (Nininger, 1978).

The requirements for current enrichment contracts are near the industry's production capability estimated for the early 1980's. Several companies have plans as yet unannounced according to DOE, which could increase production during this period. However, if the use of nuclear power increases as predicted in the administration's National Energy Plan, a production shortage will occur in the mid 1990's (Nininger, 1978). Production requirements would be met by expansion of low-cost reserves and potential resources or by use of higher cost material, in the $30 to $50 per pound category.

The costs used by the DOE are called "forward costs" (see Glossary) and do not by definition equate to market price directly. For example, Collieries Management Corporation indicates the price of U_3O_8, in 1978 dollars, will be "$49.20-$60.80 in 1980; $79.20-$100.80 in 1985; and $86.70-$110.20 in 1990." (Nucleonics Week, March 16, 1978.)

Breeder Reactors May Extend Uranium Resources

A breeder reactor produces more fuel than it consumes, and thus could extend uranium resources. However, breeder reactors are not likely to be available to lessen the short-term uranium needs of LWR's.

An alternative to the breeder is the Canadian Natural Uranium Reactor (CANDU), which reportedly can obtain 20 to 40 percent more energy from uranium than a LWR. Other reactor development concepts which do not require highly enriched uranium are being investigated to limit proliferation of nuclear material.

Uranium Enrichment

Almost 90 percent of the world's present and planned nuclear generating capacity requires slightly enriched uranium as fuel (Keeny et al., 1977). The enrichment process requires that the U_3O_8 be converted to uranium hexafluoride (UF_6), which is the input (feed) for the process. Natural uranium contains about 0.7 percent of the fissionable isotope ^{235}U. Enrichment increases the concentration of this isotope to approximately 3 percent, which is necessary to provide fuel for a light-water reactor.

Commercial quantities of enriched uranium are produced by government-owned gaseous diffusion plants. These plants are energy intensive. At full capacity the plants require 6,1000 MW of electrical power (NRC GESMO, NUREG-0002, Vol. 3, 1976). The plants not only produce the enriched UF_6 product but also UF_6 that is depleted in ^{235}U, called tails. The tails assay, expressed as the percentage of ^{235}U, at which an enrichment plant is operated, depends upon availability of uranium feed, plant capacity, and power availability. In 1980 the government will operate at an increased tails assay. At that time, the percentage will increase to 0.25 percent from 0.2 percent.

Because of the increase in the tails assay, the overall requirements for U_3O_8 concentrate will increase more than 20 percent (Keeny et al., 1977).

Recycling (Reprocessing)

There is now a moratorium on recycling spent fuel from LWR's. Domestic uranium reserves would be extended by recycling spent fuel (Boyd et al., 1977). Although recycling would ease demand, there would be a shortfall in the supply of uranium.

2.2
Uranium Supply

Estimates of domestic uranium reserves and resources follow.

	U_3O_8, Millions of Short Tons	
Reserves [known]	0.7	all that is certain
Probable maximum	3.7	upper planning limit
Prudent planning base	1.8-2.0	

Source: (Culler, 1977)

Estimates of known reserves total about 680,000 tons, and probable resources may add 1.1 million tons, resulting in a 1.8 million ton prudent planning base. The 3.7 million tons include possible and speculative resources yet to be located (Culler, 1977).

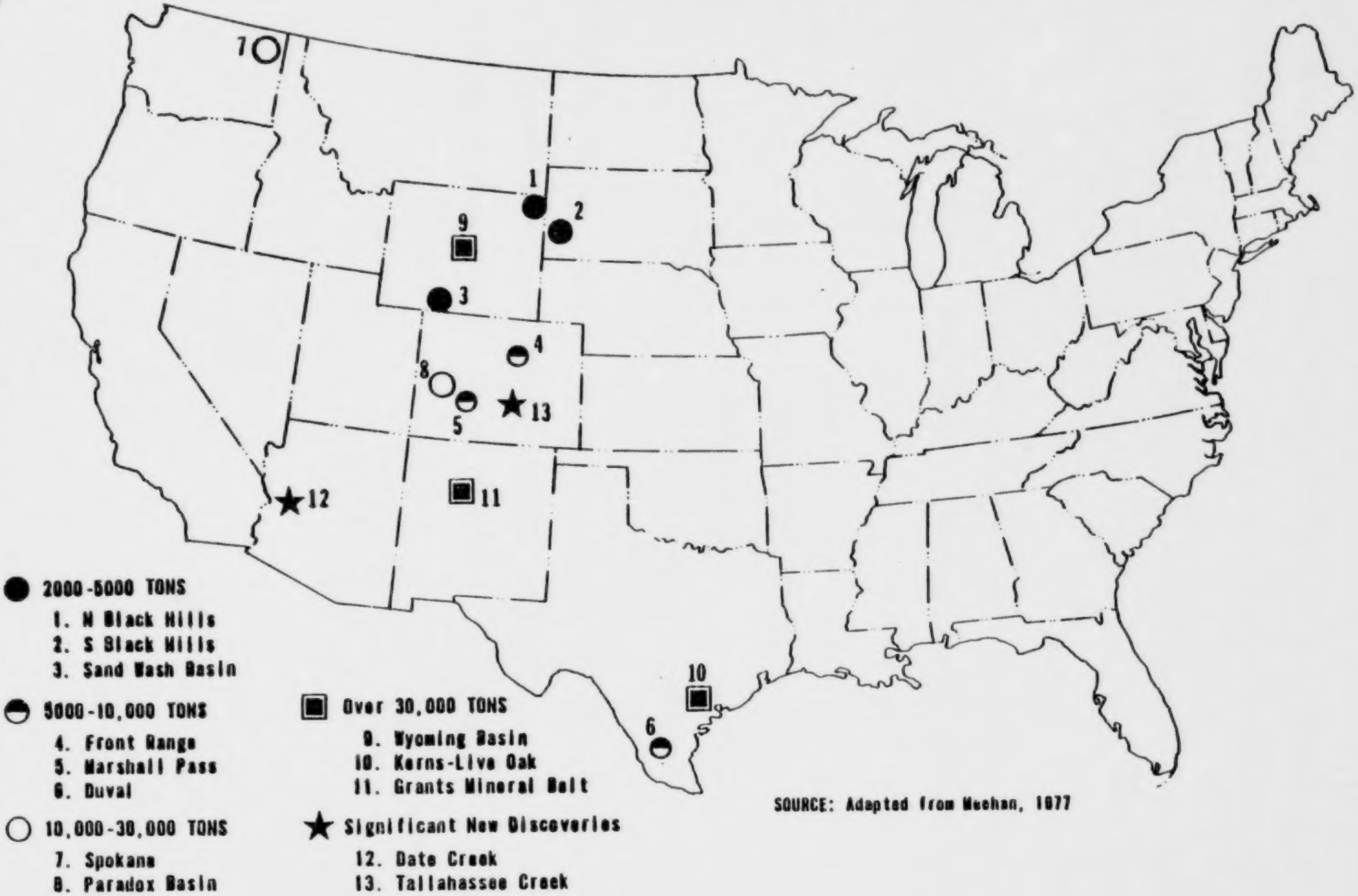
2.2.1
Uranium Ore Reserves

DOE estimates of domestic ore reserves are based largely on data furnished by industry. These data consist primarily of gamma-ray logs of drill holes and other ore deposit sampling information.

The majority of uranium reserves in the United States are in sandstones of the Mesozoic and Tertiary ages in the following comparatively small areas:

- Grants mineral belt of New Mexico
- Tertiary basins in Wyoming
- Gulf Coastal Plain in Texas
- Paradox Basin in Colorado and Utah
- Spokane area in Washington

The DOE has estimated the amount of uranium that can be exploited for a forward cost of $30/lb. The location of these reserves and the estimated amount of uranium oxide within each reserve are shown on Figure 2-4.


1
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13
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11
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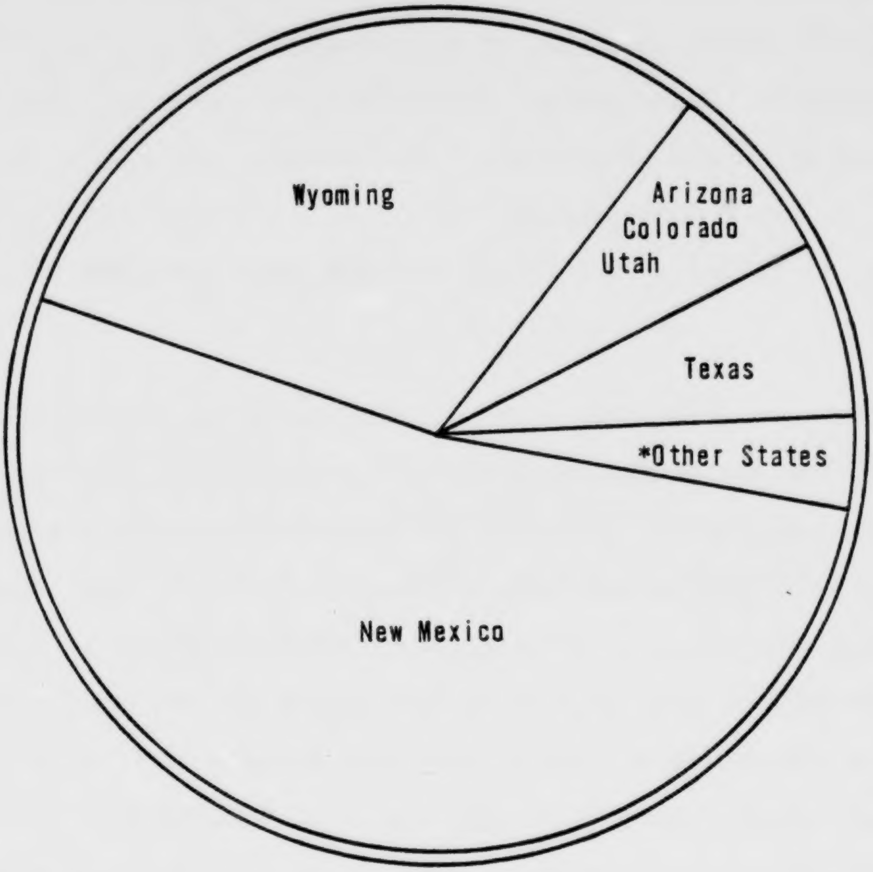
6
7
● 2000-5000 TONS
1. N Black Hills
2. S Black Hills
3. Sand Wash Basin
◒ 5000-10,000 TONS
4. Front Range
5. Marshall Pass
6. Duval
○ 10,000-30,000 TONS
7. Spokane
8. Paradox Basin
▣ Over 30,000 TONS
9. Wyoming Basin
10. Kerns-Live Oak
11. Grants Mineral Belt
★ Significant New Discoveries
12. Date Creek
13. Tallahassee Creek

SOURCE: Adapted from Meehan, 1977

Figure 2-4
Distribution of $30 Per Pound U_3O_8 Reserves as of 1/1/77 in Major Districts



*OTHER STATES

California
Idaho
Montana
Nevada
North Dakota
Oklahoma
Oregon
South Dakota
Washington

SOURCE: Nininger, 1978

STATE	THOUSANDS TONS U_3O_8	%
New Mexico	364	53
Wyoming	207	30
Texas	47	7
Ariz, Colo, Utah	52	7
Other	20	3
Total(rounded)	690	100

Figure 2-5
U.S. Reserves of $30 Per Pound U_3O_8 by States (1/1/78 Preliminary)

Each ore body must be able to support the total forward operating and capital costs in order to be recognized as a reserve. A more comprehensive discussion of forward costs, ore reserve categorization and estimation methodology is given by Meehan (1977). The distribution of U.S. uranium reserves as of January 1, 1977 for the $30/lb forward cost category is given on Figure 2-5.

Additions to reserves are likely to be in, or extensions of, presently-known producing districts, mostly in Wyoming and New Mexico. New Mexico accounts for approximately 50 percent of the uranium produced in the U.S. (Nininger, 1978). The New Mexico Environmental Improvement Agency (NMEIA) expects 15 new uranium mills to become operational in New Mexico in the next few years. Nine new mines are in the development stage and 13 more have been proposed (Rocky Mountain Energy Summary, January 23, 1978.) Many of the proposed developments will be in the San Juan Basin north of the Grants mineral belt. In northeastern Wyoming, the Sundance project is reported to have potential yellowcake reserves "in the 50 million pound vicinity believed to be economically recoverable by solution mining techniques." (Nucleonics Week, January 12, 1978.)

Other significant new discoveries are being developed in Arizona at Date Creek and the central Colorado Rockies at Tallahassee Creek (Meehan, 1977). Also, plans were announced for a uranium mine to be operating near Bakersfield, California, by fall 1978. Proven reserves total about 162,000 pounds in hard rock, not sandstone. According to reports by Portland General Electric geologists, potential reserves within 3 miles of the mine may total 5–10 million pounds (Nucleonics Week, March 2, 1978).

2.2.2
Uranium Resources

The location of new uranium-producing districts and the extent to which they will be developed are of primary interest to those who may be affected by uranium activities. Table 2-2 shows the locations of potential uranium resources and estimates of how much ore these resources may yield. Figure 2-6 is a map of National Uranium Resource Evaluation reporting regions. Table 2-3 tabulates the amount of $30/lb uranium by state. Figure 2-7 shows the location of potential uranium areas.

The DOE resource classifications, which reflect the differences in the reliability of the resource estimates, are listed in the Glossary. Additional information on estimates of ore reserves and potential resources is given in the "Statistical Data of the Uranium Industry," which is compiled by the Grand Junction Office of DOE.

Surface Drilling Activities

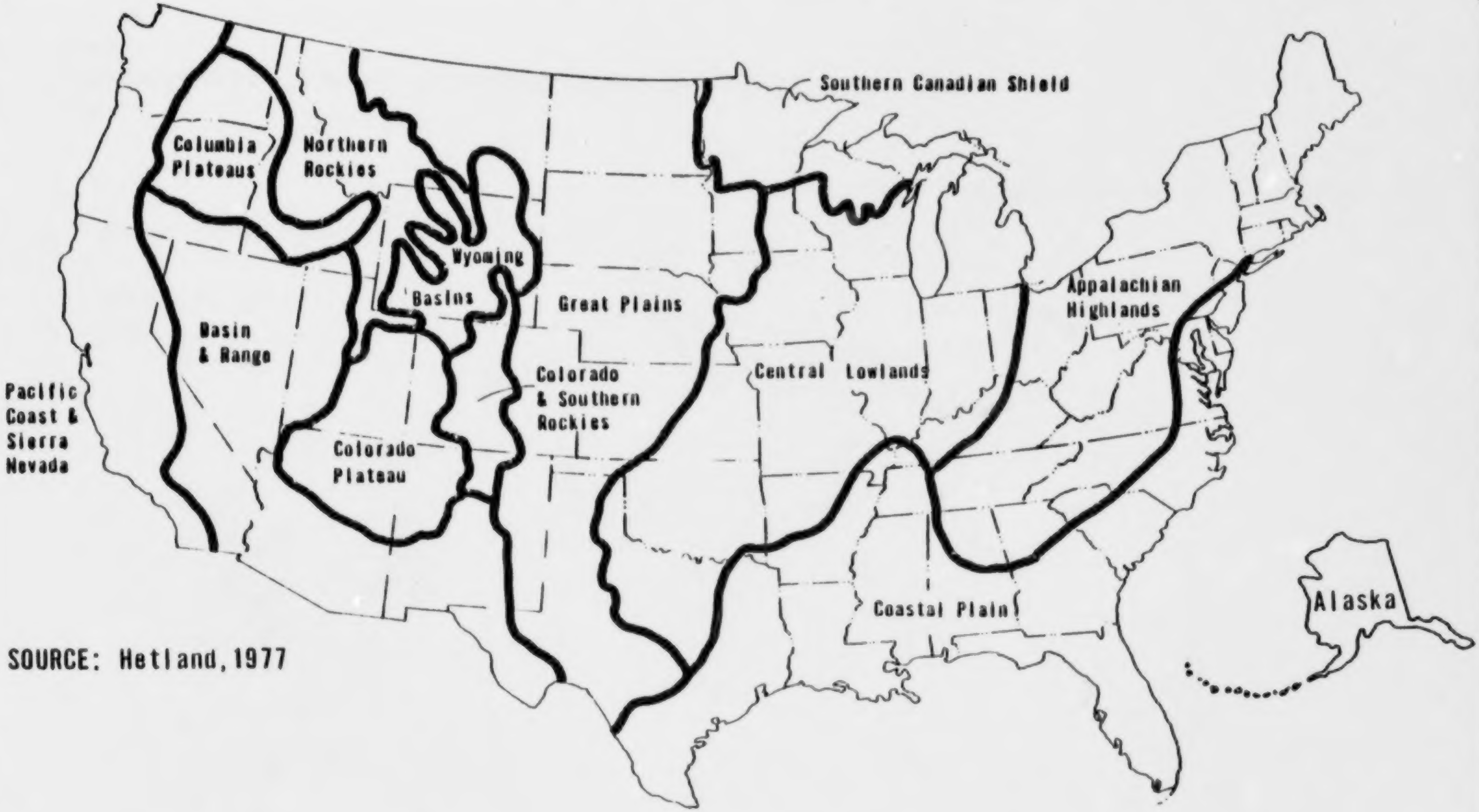
The rise in the price of uranium and the increased demand for uranium supplies have stimulated exploration in the U.S. Exploration activities have increased dramatically since 1972, and the amount of surface drilling for uranium in 1977 was the highest ever.

	Tons U_3O_8	Tons U_3O_8 ($30/lb.)			
			1/1/77 Potential Resources		
Region	Production to 1/1/77	1/1/77 Reserves	Probable	Possible	Speculative
Colorado Plateau	206,400	378,000	545,000	610,000	90,000
Wyoming Basins	63,600	210,100	300,000	50,000	30,000
Coastal Plain	8,900	43,900	115,000	60,000	25,000
Northern Rockies	16,500	20,000	27,000	63,000	49,000
Colorado and Southern Rockies		9,400	46,000	38,000	20,000
Great Plains		6,300	23,000	59,000	37,000
Basin and Range		10,900	29,000	228,000	51,000
Pacific Coast and Sierra Nevada	<1,000	1,400	4,000	12,000	8,000
Central Lowlands	<1,000	0	*	*	71,000
Appalachian Highlands	<1,000	0	*	*	78,000
Columbia Plateaus	<1,000	0	*	*	21,000
Southern Canadian Shield	0	0	*	*	*
Alaska	<1,000	0	1,000	*	*
TOTAL	296,400	680,000	1,090,000	1,120,000	480,000

*Resources not estimated because of inadequate knowledge.

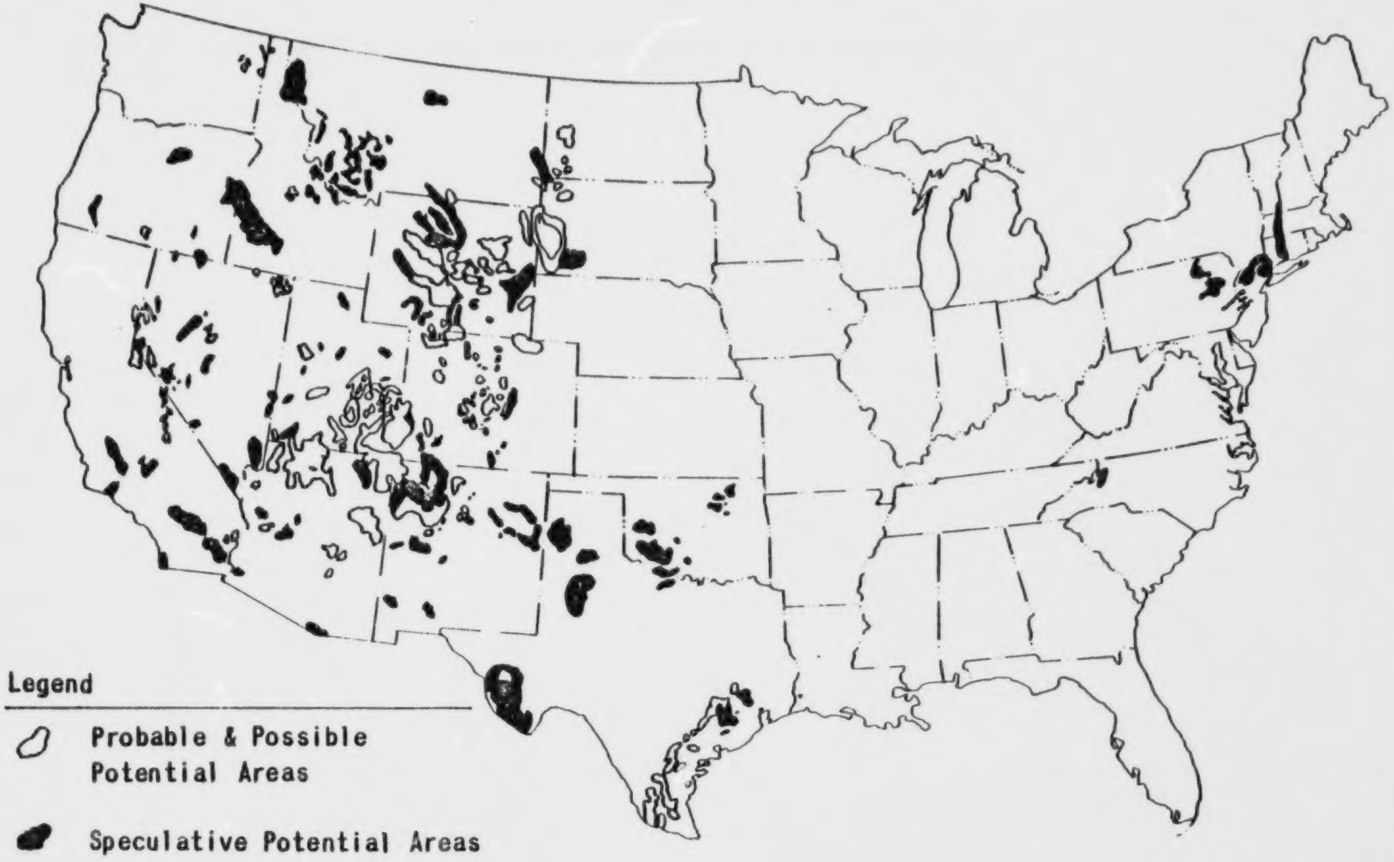
SOURCE: Hetland, 1977

Table 2-2
Summary of Uranium Production, Reserves, and Potential Resources by Regions


Southern Canadian Shield
Columbia Plateaus
Northern Rockies
Wyoming Basins
Great Plains
Appalachian Highlands
Basin & Range
Central Lowlands
Pacific Coast & Sierra Nevada
Colorado & Southern Rockies
Colorado Plateau
Alaska
Coastal Plain

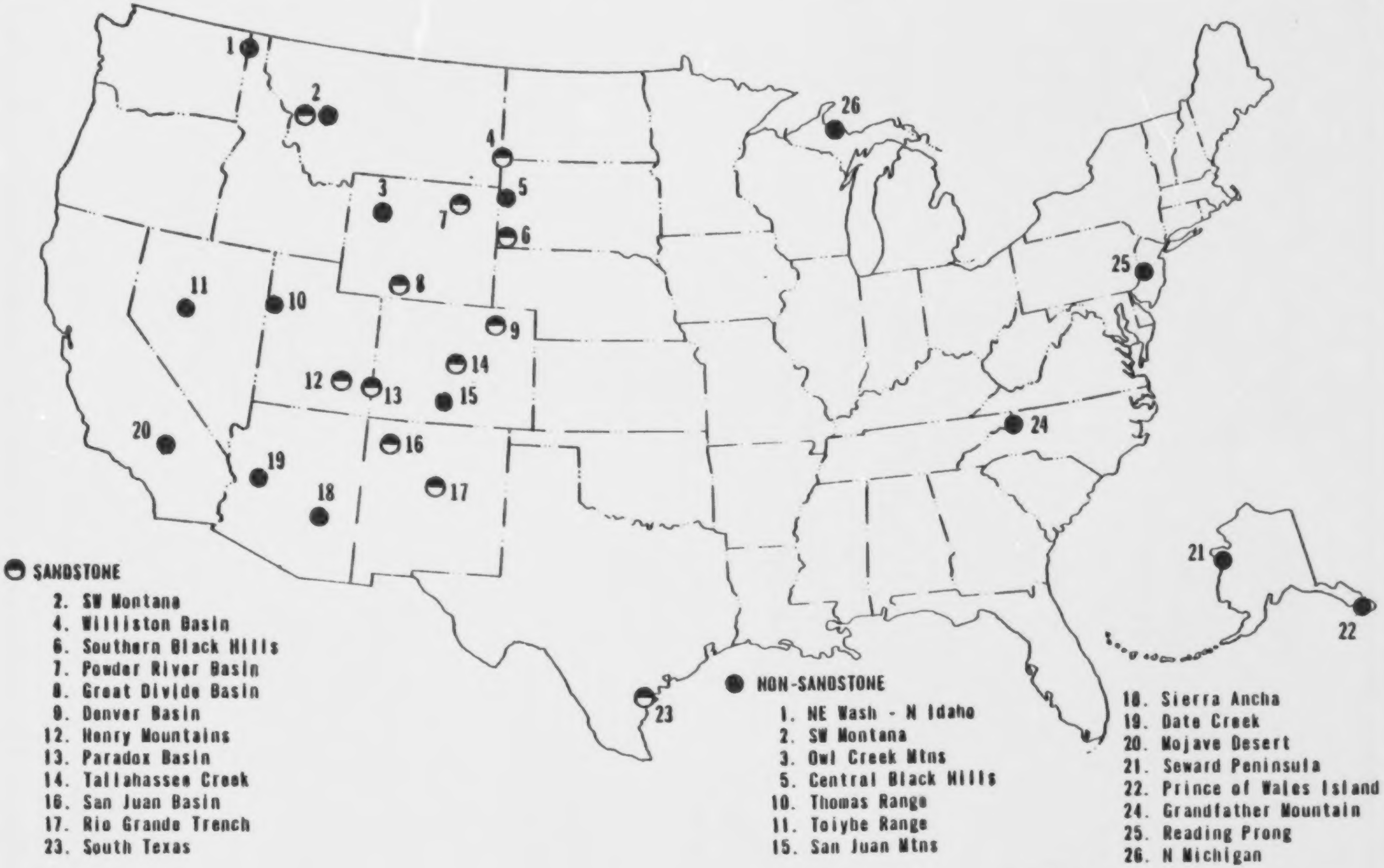
SOURCE: Hetland, 1977

Figure 2-6
Regions of the National Uranium Resource Evaluation (NURE) Program


Legend
Probable & Possible Potential Areas
Speculative Potential Areas

SOURCE: Adapted from Hetland, 1977

Figure 2-7
National Uranium Resource Evaluation (NURE) Potential Uranium Resource Areas


SANDSTONE
2. SW Montana
4. Williston Basin
6. Southern Black Hills
7. Powder River Basin
8. Great Divide Basin
9. Denver Basin
12. Henry Mountains
13. Paradox Basin
14. Tallahassee Creek
16. San Juan Basin
17. Rio Grande Trench
23. South Texas
NON-SANDSTONE
1. NE Wash - N Idaho
2. SW Montana
3. Owl Creek Mtns
5. Central Black Hills
10. Thomas Range
11. Toiybe Range
15. San Juan Mtns
18. Sierra Ancha
19. Date Creek
20. Mojave Desert
21. Seward Peninsula
22. Prince of Wales Island
24. Grandfather Mountain
25. Reading Prong
26. N Michigan
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SOURCE: Adapted from Chenoweth, 1977

Figure 2-8
Significant Exploration Activities, 1977

State	Probable	Possible	Speculative
Alaska	1,000	--	--
Arizona	37,000	50,000	11,000
Arkansas	--	--	1,000
California	11,000	10,000	8,000
Colorado	101,000	82,000	37,000
Connecticut	--	--	9,000
Idaho	--	5,000	31,000
Montana	--	7,000	43,000
Nevada	4,000	13,000	14,000
New Jersey	--	--	9,000
New Mexico	398,000	466,000	77,000
North Carolina	--	--	17,000
North Dakota	7,000	9,000	--
Oklahoma	--	--	65,000
Oregon	7,000	21,000	7,000
Pennsylvania	--	--	45,000
South Dakota	7,000	4,000	5,000
Texas	117,000	60,000	54,000
Utah	77,000	270,000	5,000
Washington	9,000	23,000	15,000
Wyoming	314,000	100,000	27,000
TOTAL	1,090,000	1,120,000	480,000

SOURCE: Hetland, 1977

Table 2-3
Distribution of $30 Per Pound U_3O_8 Potential Uranium Resources by State as of 1/1/77

Most of the exploration is concentrated in the vicinity of the major uranium-producing districts. Wyoming, New Mexico, Texas, Colorado, and Utah accounted for 92.7 percent of the surface drilling in 1977 (Nininger, 1978). Significant exploration activities in 1977 reported by DOE are shown on Figure 2-8.

Surface drilling statistics given in Table 2-4 show the rapid expansion of exploration and development drilling since the low point in 1971.

Table 2-4

Summary of Surface Drilling for Uranium

YEAR	MILLIONS OF FEET	THOUSANDS OF HOLES	AVE. HOLE DEPTH IN FEET	PERCENT EXPLORATION DRILLING	PERCENT DEVELOPMENT DRILLING
1968	24	30	410	68	32
1969	30	58	394	69	31
1970	24	76	400	76	24
1971	15	59	398	74	26
1972	15	39	421	78	22
1973	16	37	480	66	34
1974	22	34	550	73	27
1975	27	40	457	65	35
1976	35	67	506	57	43
1977	40	94	434	64	36

Source: Nininger, 1978

Other Exploration Activities

Industry and DOE have recently increased their exploration activities, such as geologic mapping and geochemical and geophysical surveying, in new areas. The success of exploration in frontier areas remains to be demonstrated (Chenoweth, 1977).

Production from Lower Grade Ores

Production estimates for 1985–1990 are difficult to project because of the problems with development of lower-grade uranium ore. Yellowcake production in 1977 was estimated as 15,000 short tons (Kahn, 1977) from ore of a higher grade than would be expected in the 1980's and 1990's. Development of future uranium supplies will be tied directly to world-wide demand. The selling price of uranium oxide extracted from lower-grade ores is expected to be higher.

2.2.3
Future Uranium Production Centers

The DOE Supply Analysis Division has analyzed existing, expanded, and proposed uranuim mining and milling capabilities in the U.S. The production centers are shown on Figures 2–9A and 2–9B. The DOE projections should prove helpful to planners in that the projections are for a relatively long time span.

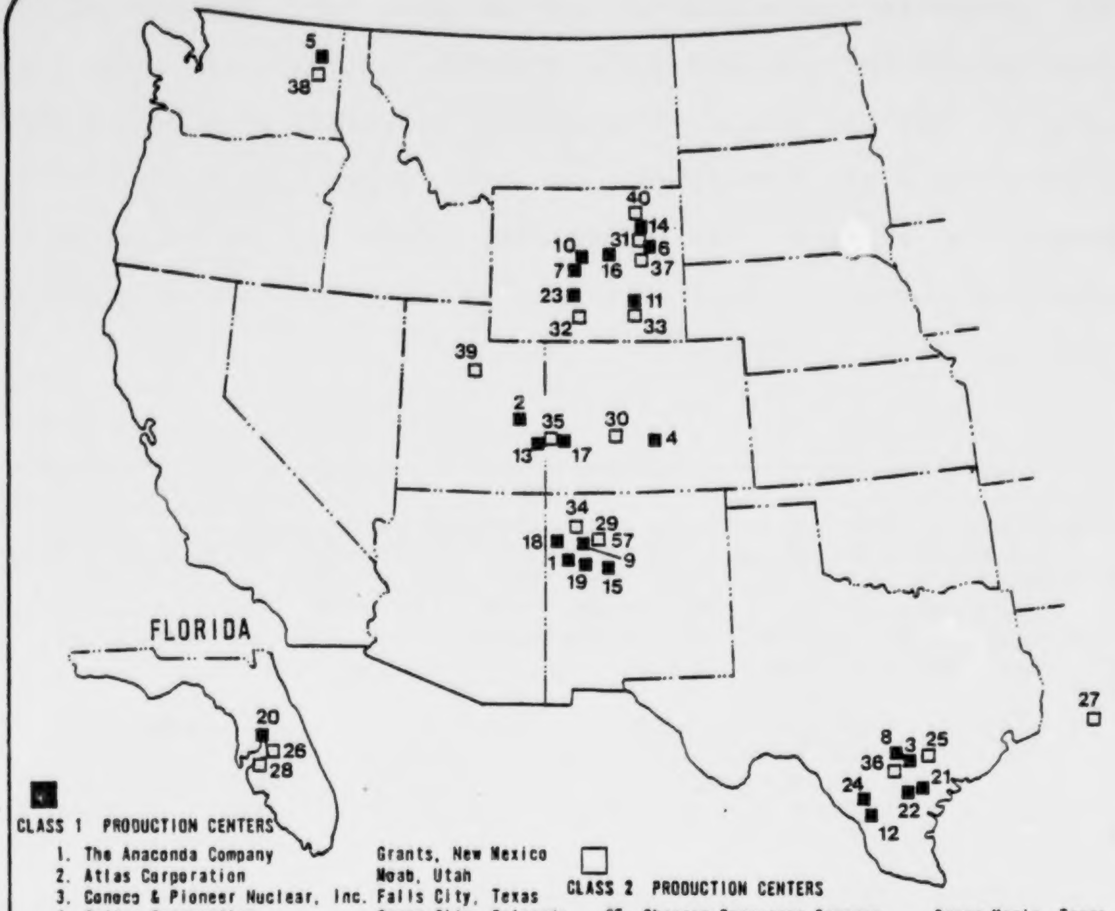
The production capabilities are an upper limit estimate of how much uranium the industry could produce. It appears that the estimate does not include financing or licensing constraints that might alter mine development or mill construction schedules. Production centers were classified according to certainty of future production. The classifications are excerpted as follows (Klemenic et al., 1977):

- CLASS 1 CENTERS include the existing mills with supporting mines and other facilities at which concentrate was being produced at the time the capability estimate was made. Ownership of the facilities and tributary sources can readily be identified. Production costs can reasonably be defined, and future production is well assured.

- CLASS 2 CENTERS include uranium mills and supporting resources for which construction commitments are evident and mine development has been announced or is underway. Class 2 centers are generally converted to Class 1 centers within three years.

- CLASS 3 CENTERS are uranium mills in regions where the amount and grade of reserves justify production but where mill construction is not yet evident. Three to five years are estimated for mine and mill installation.

- CLASS 4 CENTERS are possible centers postulated for areas in which present reserves are insufficient to support production facilities but where exploration and/or geologic evidence has indicated sufficient "probable" potential resources to warrant the assumption of eventual production. The assummed lead time to develop reserves and construct mining and milling facilities for Class 4 centers generally ranges from 6 to 22 years and averages 14 years. Consolidation of land holdings is a long lead-time item.



■ CLASS 1 PRODUCTION CENTERS

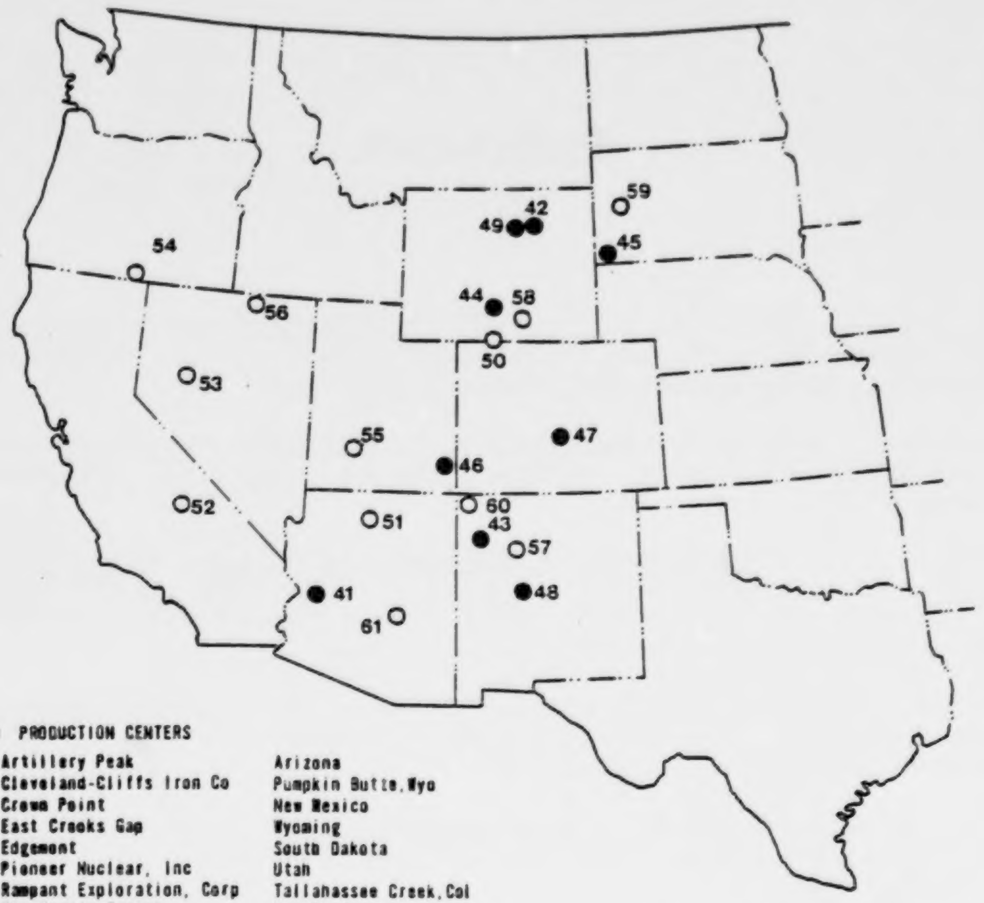
1.	The Anaconda Company	Grants, New Mexico
2.	Atlas Corporation	Moab, Utah
3.	Conoco & Pioneer Nuclear, Inc.	Falls City, Texas
4.	Cotter Corporation	Canon City, Colorado
5.	Dawn Mining Company	Ford, Washington
6.	Exxon Company, U.S.A.	Powder River Basin,Wyo
7.	Federal American Partners	Gas Hills, Wyoming
8.	Intercontinental Energy Corp.	Pawnee, Texas
9.	Kerr-McGee Nuclear Corp.	Grants, New Mexico
10.	Lucky Mc Uranium Corporation	Gas Hills, Wyoming
11.	Lucky Mc Uranium Corporation	Shirley Basin, Wyo
12.	Mobil Oil Company	Bruni, Texas
13.	Rio Algom Corporation	La Sal, Utah
14.	Rocky Mtn. Energy Company	Bear Creek, Wyo
15.	Sohio Oil-Reserve Oil	Laguna, New Mexico
16.	Union Carbide Corporation	Gas Hills, Wyoming
17.	Union Carbide Corporation	Uravan, Colorado
18.	United Nuclear Corporation	Church Rock, N.M.
19.	United Nuclear Homestake-Partners	Grants, New Mexico
20.	Uranium Recovery Corp.	Mulberry, Florida
21.	U.S. Steel	George West, Texas
22.	U.S. Steel-Niagra Mohawk	George West, Texas
23.	Western Nuclear, Inc.	Jeffrey City, Wyoming
24.	Wyoming Mineral Corporation	Bruni & Ray Point, Texas

□ CLASS 2 PRODUCTION CENTERS

25.	Chevron Resources Company	Panna Maria, Texas
26.	Farmland Industries, Inc	Pierce, Florida
27.	Freeport Uranium Recovery Co	Uncle Sam, Louisianna
28.	Gardinier, Inc	Tampa, Florida
29.	Gulf Mineral Resources Co	San Mateo, New Mexico
30.	Homestake Mining Company	Marshall Pass, Colo
31.	Kerr-McGee Nuclear Corp	Powder River Basin,Wyo
32.	Mineral Exploration Company	Red Desert, Wyoming
33.	Petrotomics Company	Shirley Basin, Wyo
34.	Phillips Petroleum Company	Nose Rock, New Mexico
35.	Durita Development Company	Naturita-Durango, Col
36.	Solution Engineering, Inc	Falls City, Texas
37.	United Nuclear Corporation	Morton Ranch, Wyoming
38.	Western Nuclear, Inc	Wellpinit, Wash
39.	Wyoming Mineral Corp	Bingham, Utah
40.	Wyoming Mineral Corp	Powder River Basin,Wyo

SOURCE: Adapted from Klemenic, 1977

Figure 2-9A
Class 1 and Class 2 Production Centers in the United States
\$30 Per Pound U_3O_8



● CLASS 3 PRODUCTION CENTERS

41.	Artillery Peak	Arizona
42.	Cleveland-Cliffs Iron Co	Pumpkin Butte, Wyo
43.	Crown Point	New Mexico
44.	East Crooks Gap	Wyoming
45.	Edgemont	South Dakota
46.	Pioneer Nuclear, Inc	Utah
47.	Rampant Exploration, Corp	Tallahassee Creek, Col
48.	Rio Grande Trench	New Mexico
49.	Rocky Mountain Energy Co	Copper Mtn, Wyo

○ CLASS 4 PRODUCTION CENTERS

50.	Baggs	Wyoming
51.	Cameron	Arizona
52.	Case	California
53.	Fernley	Nevada
54.	Lakeview	Oregon
55.	Marysvale	Utah
56.	Mountain City	Nevada
57.	Mt. Taylor	New Mexico
58.	NE Great Divide Basin	Wyoming
59.	North Black Hills	South Dakota
60.	Shiprock	New Mexico
61.	Sierra Ancha	Arizona
Other Copper Operations By-Product		Western U.S.
Other Phosphate By- Prod.		SE & W U.S.

SOURCE: Adapted from Klemenic, 1977

Figure 2-9B
Class 3 and Class 4 Production Centers in the United States $30 Per Pound U_3O_8

CHAPTER 2

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CHAPTER 3

Mining and Milling Uranium Ore

Uranium development projects must operate within the framework of acceptable mining and milling technology. General understanding of the current state of this technology is necessary in order to compare siting options and development processes in respect to environmental and socioeconomic concerns. Current practices in mining and milling uranium ores are summarized under the following topics:

- Overview of uranium resource development
- Uranium mining
- Uranium processing methods
- Production costs
- Mill tailings management

3.1
Uranium Resource Development

Successful uranium resource development depends upon comprehensive planning prior to mining and milling. The following sections briefly discuss the planning steps and provide an overview of the common processing stages and methods.

3.1.1
Steps Prior to Mining and Milling

Once a uranium ore body has been located and the necessary permits and licenses have been obtained, exploration drilling is followed by development drilling to determine the grade, size, depth and shape of the deposit. The drilling provides samples which are analyzed to identify the physical and chemical properties of the ore. Samples from the deposit are also tested to determine the process necessary to extract uranium from the ore and recover the material as a marketable product. Site surveys and preliminary mine-planning studies are usually conducted simultaneously with the process development investigation. A series of coordinated site-surveys is performed to provide data relative to soil mechanics, hydrology, topography, meteorology, vegetation and wildlife, public health and sanitation, labor resources, transportation and available sources of material and equipment. Assuming the ore responds favorably to treatment, the data collected from the process development studies and site surveys are used to conduct preliminary mill-engineering studies and to determine the economic feasibility of the project. If the economics appear favorable, financing is arranged, environmental factors are assessed, a mill site is selected and detailed engineering is initiated (O'Rourke and Whelan, 1968).

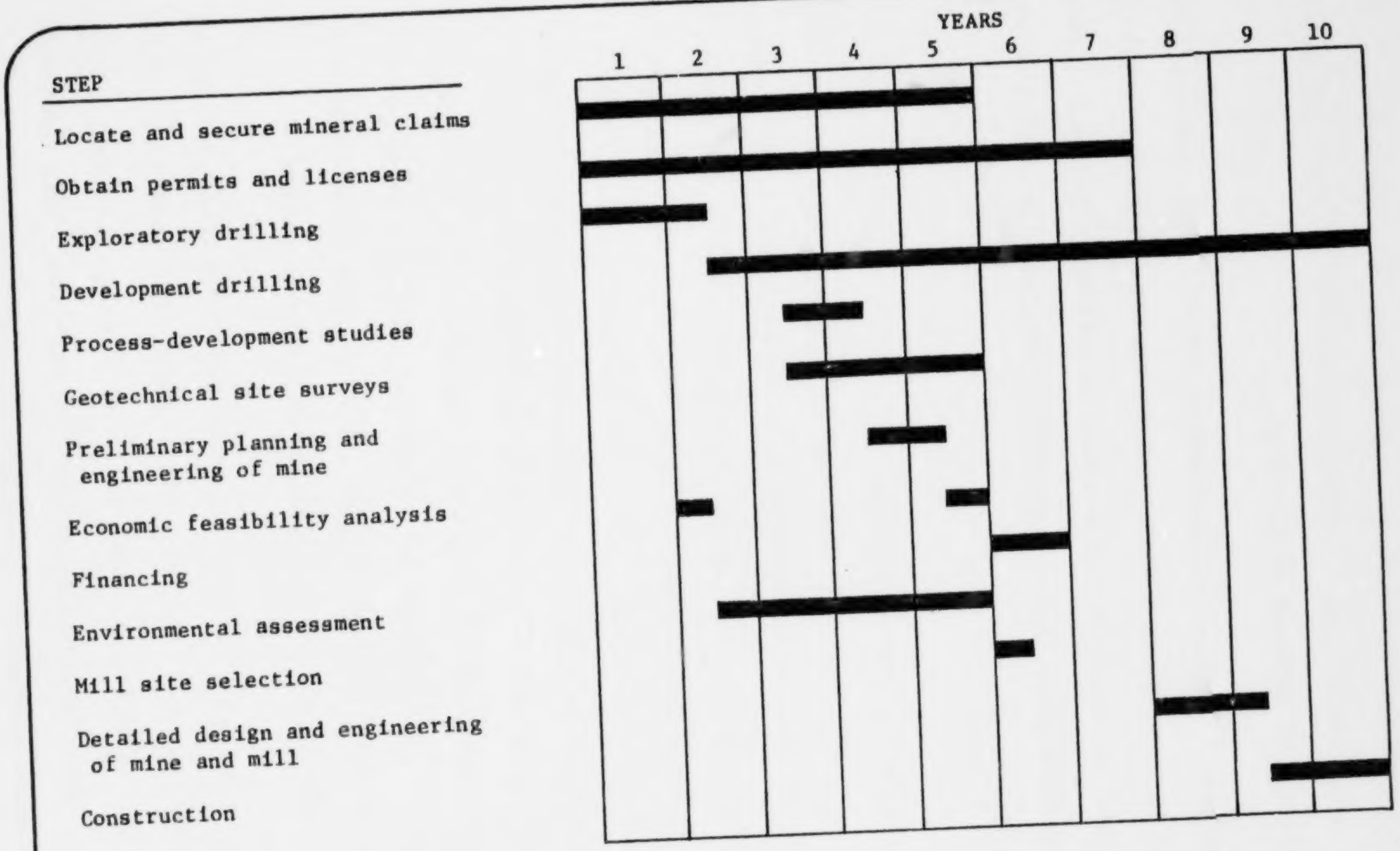
Developing a uranium prospect is similar to developing other mineral deposits except that regulatory controls are strictly enforced by the NRC or one of the agreement states in accordance with the Atomic Energy Act of 1954 as amended. Accordingly, many federal, state and local government agencies must be consulted, and ultimately their approval to proceed must be obtained. The licensing and permitting process may result in long lead times for development of uranium properties.

After licenses, permits and approvals are secured, construction of the mine-mill complex begins. Development usually requires several years to complete. The exact development route followed by companies will vary, but a simplified program is illustrated on Figure 3-1.

3.1.2
Methods to Mine and Process Uranium Ore

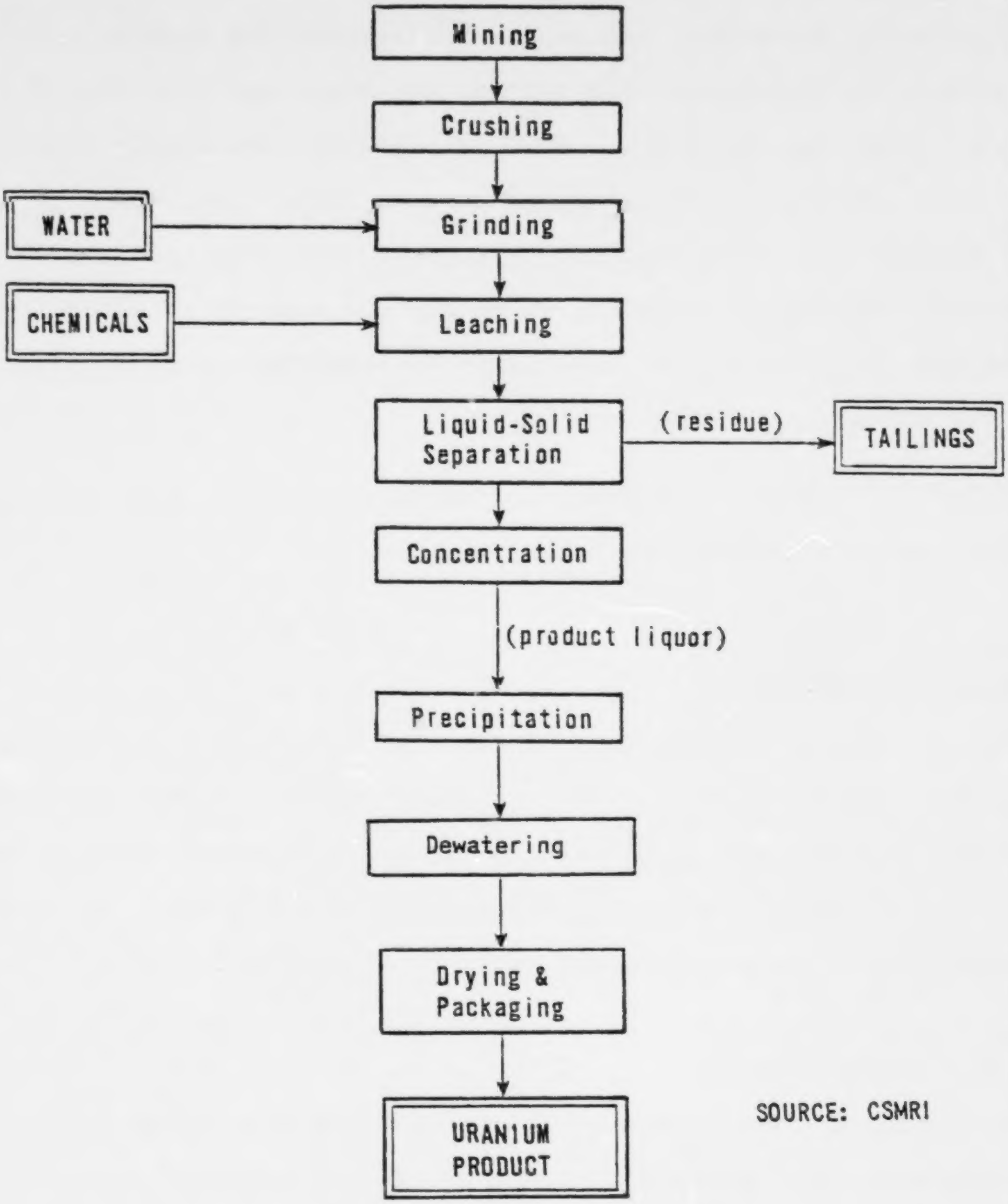
A variety of methods are employed by the industry to mine and process uranium ore. Most methods have several steps in common. As illustrated on Figure 3-2, the uranium-bearing ore is mined and transported to the processing facility. The ore is crushed and ground to expose the uranium minerals on the surface of barren host-rock particles. The ground ore is pulped with water, and chemicals are added to dissolve the uranium. The dissolved uranium is separated from the leached residue, and the uranium-bearing liquor is treated by selective chemical techniques to yield a uranium-rich product liquor. The uranium is precipitated from this liquor, dried and shipped to enrichment plants.

One notable exception to this general mining-milling scheme is the in-situ extraction of uranium from intact ore bodies. This technique is relatively new to the mining industry, and relatively few deposits are presently treated in this manner. Basically, in-situ extraction (solution mining) involves drilling



SOURCE: Adapted from CSMRI, 1978

Figure 3-1
Steps in Uranium Resource Development


Mining
Crushing
WATER
Grinding
CHEMICALS
Leaching
Liquid-Solid Separation
(residue)
TAILINGS
Concentration
(product liquor)
Precipitation
Dewatering
Drying & Packaging
URANIUM PRODUCT

SOURCE: CSMRI

Figure 3-2
Steps Common to Most Processing Methods

a series of wells into a permeable uraniferous aquifer, injecting a leaching agent into the wells, and pumping the uranium-bearing solution to the surface for further treatment and recovery of the U_3O_8 (See Figure 3-8). This eliminates the costly steps of mining, crushing, and grinding and reduces the above-ground deposition of mill tailings. However, the long term impact of in-situ extraction on ground water and the methods to effectively restore solution-mined aquifiers to premining or to acceptable water quality are being studied.

Table 3-1 lists the process variations for open pit and underground mines and for solution mining.

3.2
Uranium Mining

Uranium mining methods fall within the categories of underground mining, surface mining, and bore-hole mining. The preferred method is the one that requires the least cost per pound of ore recovered while remaining within the constraints of many technical, environmental, and regulatory factors.

3.2.1
Mining Method Selection

Selection of the mining method is based on a detailed geologic, engineering and economic analysis of the ore deposit. Factors to be considered are the ore body's size, grade, host-rock mechanics, location, depth, geometry and engineering properties.

Open-Pit Mines	Underground Mines	Solution Mining
Development drilling	Development drilling	Development drilling
Stripping*	Shaft sinking*	—
Mine waste*	Development drifting	—
Waste dump*	Waste dump*	—
Develop ore faces	Develop stopes	Drill wells
Drill, blast*	Drill, blast	Leach uranium
Load	Muck out	—
Haul	Haul	—
—	Hoist	—
—	Haul to mill	Pump solution to mill
Crush*	Crush*	—
Grind*	Grind*	—
Leach uranium	Leach uranium	—
Liquid-solid separation	Liquid-solid separation	Liquid-solid separation
U_3O_8 concentration	U_3O_8 concentration	U_3O_8 concentration
Precipitate, dry, package	Precipitate, dry, package	Precipitate, dry, package
Tailings dam* operations	Tailings dam* operations	Recirculate leach solutions
Reclamation	Reclamation	Aquifer restoration
16	18	9

Total stages to produce a saleable product

SOURCE:
Adopted from
Hunkin, October,
1975

NOTE:
* Denotes stages generally producing significant changes in or affecting land surfaces, water quality, personnel safety or radiation exposure.

Table 3-1
Process Variations at U.S. Uranium Mines and Mills

Size and Grade of the Ore Body

The boundaries of naturally occurring uranium deposits are seldom easily defined, and the mineralization grade usually varies from barren to mineralized rock. Although methods for selective mining are available, it is still impossible to distinguish completely between barren and mineralized material. The mining plan is based on information from development drilling and normally contains an allowance for dilution of the ore during mining.

Unit costs for moving ore and waste are normally less in a surface operation than for underground mines because the larger machines used are more efficient and productivity is greater. As a result, surface mining is preferred whenever the ore body is sufficiently large and close to the surface so that waste removal costs (stripping ratio) are not excessive.

Geographic Location of the Ore Body

The location of an ore body is a major factor in making the decision to proceed with mine design and evaluation. If an ore body is located within a specially designated public land (e.g., a wilderness area), mining may not be allowed. As more public lands are reserved for special uses, (e.g., the Alaska Wilderness) the number of the potential uranium reserves available for development is reduced.

Depth and Geometry of the Ore Body

Depth and geometry of the ore body have a definite impact on the mining method selected. Open pit uranium mining is practiced to depths of 400 feet, but the grade of the ore and the size of the deposit dictate the practical depth of a surface mine. Small, high-grade deposits can often be mined more efficiently by underground methods even though they may be located within a few hundred feet of the surface. A large blanket-type deposit could be more easily mined by open-pit methods even if depths are equivalent.

Engineering Properties of the Ore and Waste

Mine design must take into account the engineering properties of the ore, waste rock, and material surrounding the ore deposit(s). Underground mining requires sufficient rock strength and competency to economically prevent failure of mine walls, roofs and pillars. In surface mining, rock strength determines the slope of the pit walls required to maintain slope stability.

The presence of ground water may reduce rock strength by increasing pore pressure in the material. The result may be the failure of the surrounding rock and a cave-in in an underground mine or flooding and wall collapse in a surface mine. Ground water may also soften shale beds, allowing pillars in an underground mine to punch into the surrounding rock, resulting in a roof fall. Intrusion of large volumes of ground water into an underground or surface mine requires costly pumping and treatment systems; for example, the Mt. Taylor mine in New Mexico has a 13,000-gpm capacity pumping system (Jackson, 1977).

3.2.2
Underground Mining

Underground mining has the advantage of selectivity. The only waste materials removed are those associated with the ore body or from adits, access tunnels and shafts. On the other hand, because underground mining methods are costly, they are selected only when other methods are impractical, such as when the ore body is at too great a depth for surface development. Also, underground mining is more labor-intensive because of confined work spaces and smaller capacity machines used. Special provision must be made for access, haulage systems and ventilation.

Access

In an underground mine, access to the ore is generally by means of a vertical shaft, a sloped incline or decline, or a relatively level tunnel or adit. Tunnels are generally preferred because they can be driven so that natural drainage will occur and ore haulage is less difficult. However, tunnels are only feasible where topography allows the portal to be located at an elevation near that of the ore body. Typical examples of tunnel or adit access are the underground mines of the Federal-American Partners in the Gas Hills of Wyoming and the older workings of the Schwartzwalder Mine in Colorado.

A vertical shaft project is being constructed at Mt. Taylor, New Mexico, by Gulf Mineral Resources Co. (Jackson, 1977). The ore body is approximately 3,200 feet below the surface of the ground in an area of relatively flat terrain. Two vertical, concrete-lined shafts at a maximum depth of 3,300 feet will provide access to the ore body and sumps for mine water that must be pumped to the surface and ventilation. The shafts are 400 feet apart. A 24-ft diameter main shaft will provide a hoisting capacity of 4,500 tpd from the ore body by means of two skips powered by a 2,500-hp double drum hoist. The main shaft also serves as the air exhaust for the mine. A smaller, 14-ft diameter shaft serves as the intake shaft for ventilation and provides access for men and materials.

Mine Transportation

Mine transportation or haulage systems are required to move ore and wastes out of the mine or to the bottom of the shaft and to move men and supplies into the mine. Typically, conveyor belts, rubber-tired trucks or rail systems are used. Truck and rail systems are preferred in uranium mines. The advantages of each system are compared in Dwosh, (1978).

Tunnels and drifts are usually driven in waste rock so that extraction of the ore and subsequent subsidence will not damage the mine transportation and ore haulage systems. The tunnels and drifts also provide conduits for the ventilation system.

Ventilation

The mine ventilation system must remove all fumes from equipment, explosions, etc., and must also reduce dust and radon gas concentrations to below regulatory levels. Ventilation requirements vary from state to state, and careful attention to ventilation system design is required.

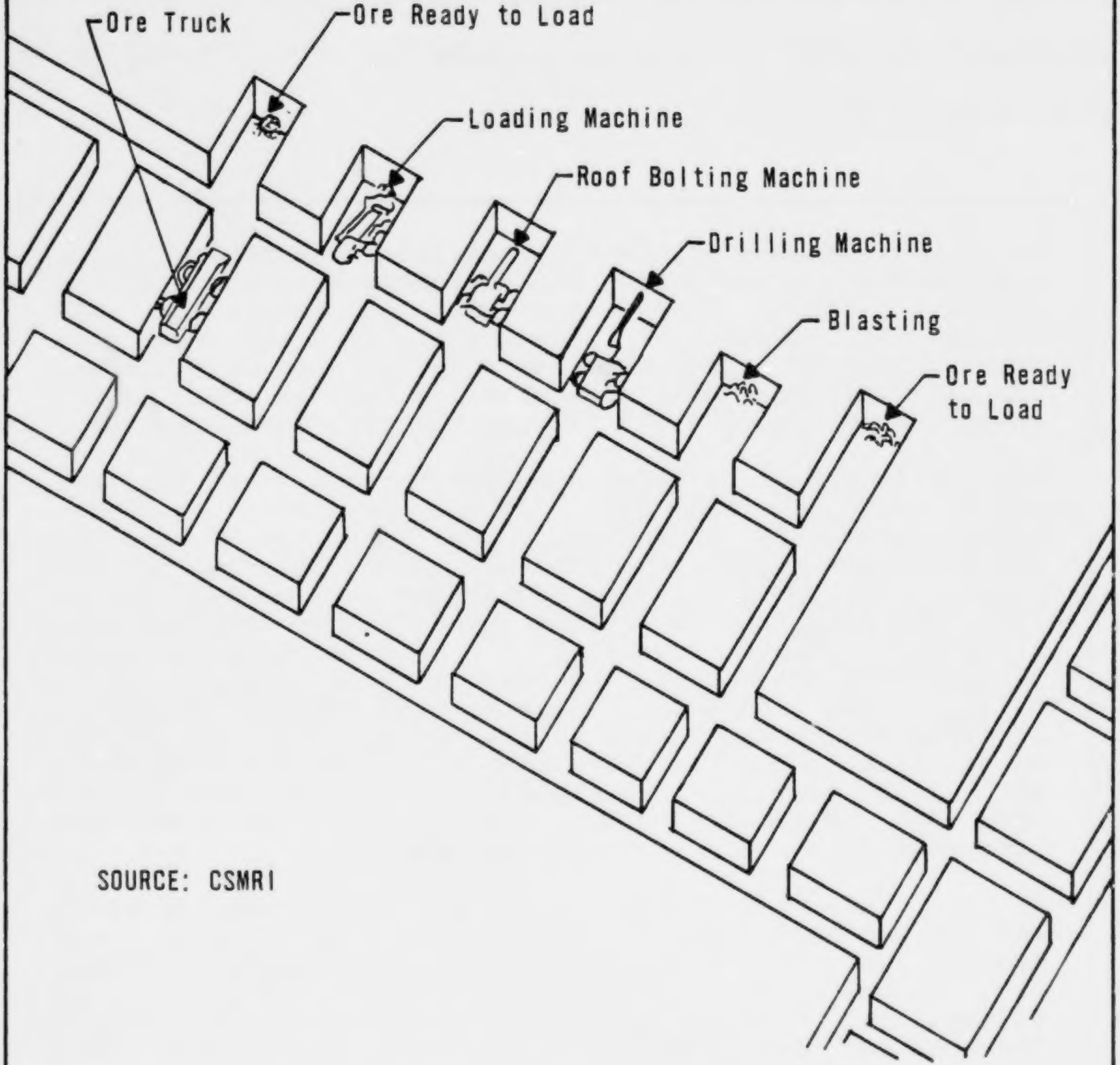
Room-and-Pillar Mining

A common mining method in tabular ore bodies is called the room-and-pillar method, illustrated on Figure 3-3. There is a high degree of flexibility in room-and-pillar mining. Work is done by equipment sections. A section might consist of a wheel or crawler type of loader, drill, and one or more rubber-tired trucks or buggies to haul the ore. The successful use of this type of equipment depends upon having a sufficient number of working places so that each machine can be rotated from place to place as its function is completed. This requires a sufficient number of working places in a reasonably confined district and close supervision on the part of the section foreman.

Thinning or thickening of the ore body, barren zones and poor roof conditions may be handled easily by the room and-pillar method. When the ore body is quite regular, the rooms and pillars are uniform in size and equally spaced as previously shown. However, when the ore body is irregular, as is the case in most uranium deposits, a system of room-and-random-pillar mining is generally used. Pillars are generally left whenever waste material is encountered, but if ore pillars must be left, they may be recovered just before the mine is abandoned when caving of the stopes is no longer a problem.

Open Room With Random Pillar Mining

Mining of ore by the open room with random pillar method begins on either an outcrop (rare occurrences at this late date for new mines) or at an ore intercept in an exploration hole at the


Ore Truck
Ore Ready to Load
Loading Machine
Roof Bolting Machine
Drilling Machine
Blasting
Ore Ready to Load

SOURCE: CSMRI

Figure 3-3
Room-and-Pillar Mining

terminus of the drift or entry. Development then generally progresses along the ore trend with attempts being made to stay in ore. As the ore bodies broaden beyond 20 feet wide, and depending on roof conditions, pillars are left in waste or low grade ore, if possible.

A typical example of a small open room with random pillar uranium mine is the Deremo Mine operated by Union Carbide (Harvey, 1977). The Deremo Mine is located on the Colorado-Utah state line approximately 64 miles from the Four Corners and about 80 miles road distance from Uravan. The mine workings cover an area 8,500 feet in the north-south direction by 6,500 feet in the east-west direction.

The Deremo Mine is being serviced through three vertical shafts about 750 feet deep. A three-compartment timbered shaft named the Deremo No. 1 was sunk in 1957, and the first ore was hoisted in 1958. As mining advanced to the south, additional hoisting facilities were needed, and in 1967, the Deremo No. 2 and the Snyder shafts were put into operation. These consisted of 64-inch diameter holes drilled from the surface and lined with a 48-inch metal casing. The annulus is filled with cement. Four-inch heavy-duty pipe was welded to the casing, and this serves as a shaft guide for the skips as well as for compressed air and water lines. The haulage system at the Deremo Mine was originally rail, but by 1971 it had been converted from track to trackless haulage.

A total of 103,000 tons of ore and 90,000 tons of waste was removed from the mine during 1976. All loading and hauling of muck from the face to shaft station is done with rubber-tired trackless equipment. Drilling is accomplished with compressed air-driven push-feed drills. The rock is broken with conventional explosives. The average output for production crew personnel is 24 tons of ore and waste per man-shift and for all mine personnel is 6.9 tons per man-shift.

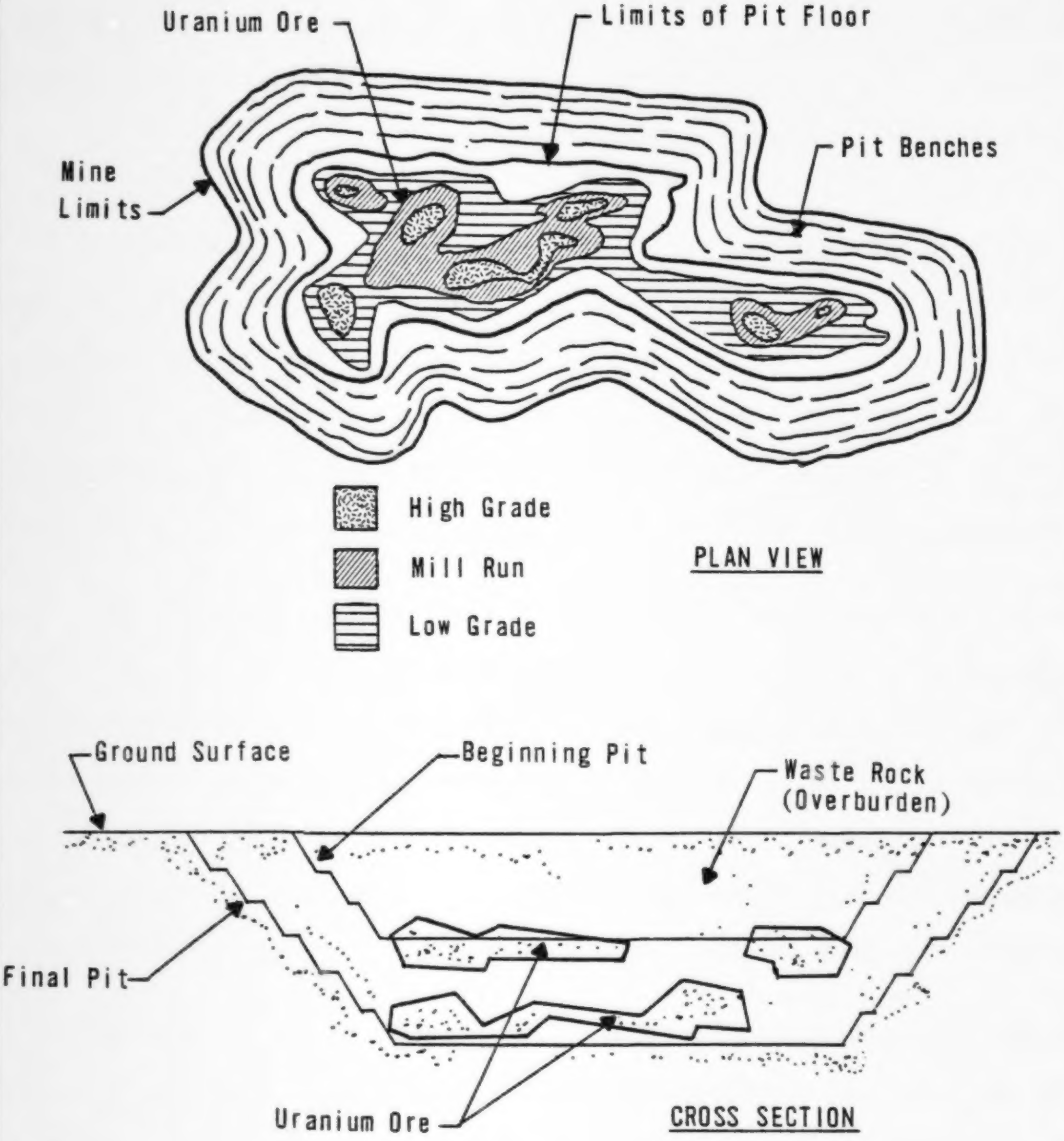
3.2.3
Surface Mining

Frequently, an ore body is large enough and close enough to the surface that it may be mined by surface or open-pit methods. An example of surface mining in flat terrain is shown on Figure 3-4. Unit operations are the same as for underground mining; however, the auxiliary requirements are not as complex, and the overall operation is generally less costly.

Generally, an extremely large excavation is required to get at a fairly small tonnage of ore. In many uranium mines, from 10 to 20 tons of waste must be removed for each ton of ore mined and occasionally, the stripping ratio may exceed 30 to 1. Stripping ratios of up to 80:1 could be encountered (Goodier, 1978).

Rock breakage in open pits is often accomplished with conventional drilling and blasting methods, but in uranium mines the strata are frequently soft enough so that crawler tractor mounted rippers may be used. Rock loading may be done by shovels or front-end loaders or by self-propelled scrapers. Haulage is accomplished by trucks or scrapers. Frequently, mine fleets include a number of each of these units.

Surface mining methods are used in uranium mines in the Gas Hills and Shirley and Powder River Basins in Wyoming, Laguna District of New Mexico and in south Texas, and in several areas in Colorado and Utah. A number of excellent papers on open-pit mining describe operations in these states (Wood, 1977; White, December, 1975; "Conquista...", Mining Engineering, 1972).


Uranium Ore
Limits of Pit Floor
Mine Limits
Pit Benches
High Grade
Mill Run
Low Grade
PLAN VIEW
Ground Surface
Beginning Pit
Waste Rock (Overburden)
Final Pit
Uranium Ore
CROSS SECTION

SOURCE: Adapted from CSMRI

Figure 3-4
Typical Open Pit Mining Method

A typical open-pit mine is the Utah International Inc.'s Lucky Mc, located in the Gas Hills of Wyoming. Wheel tractor scrapers push-loaded by bulldozers were the initial machines used for the overburden removal. However, as pit depths increased, a shift to shovel or loader and truck fleets were used because of the more favorable machine-to-payload weight ratios obtained with trucks.

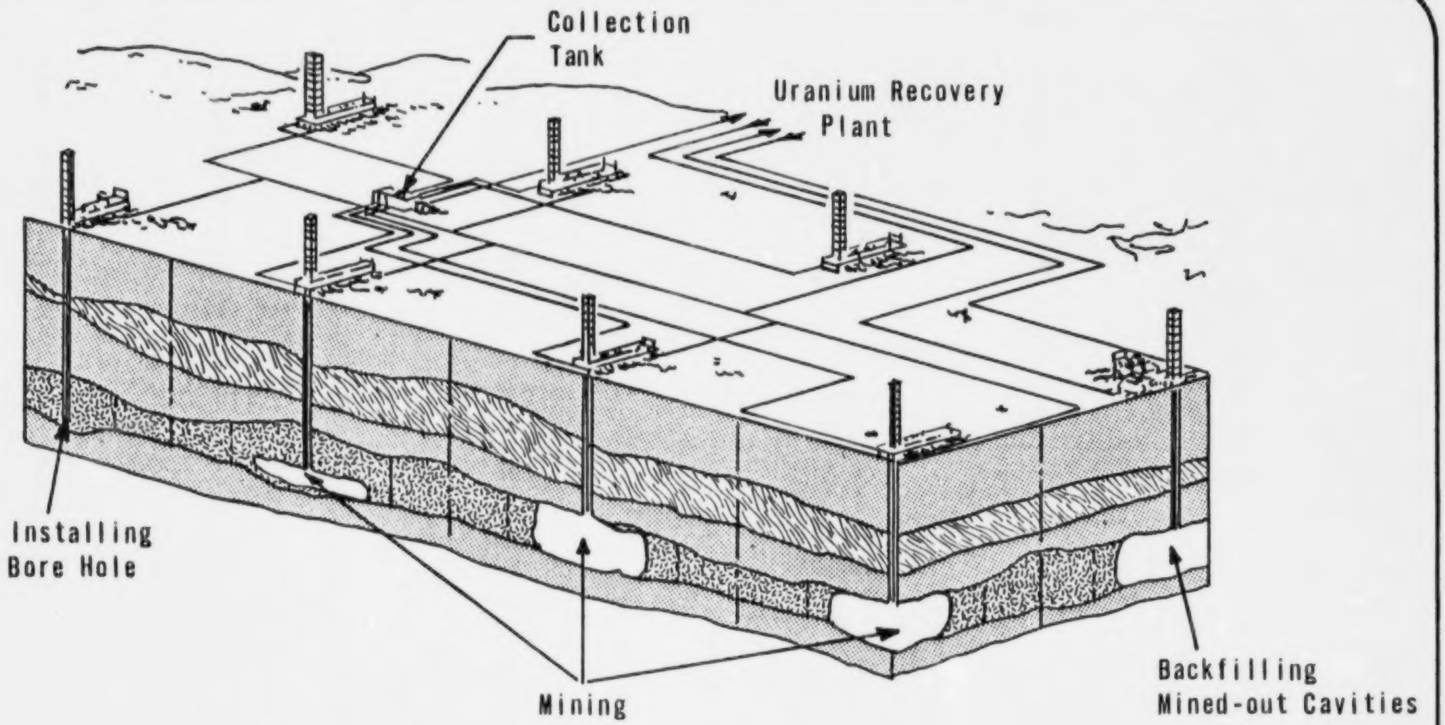
Ore trends at Lucky Mc are quite narrow, sinuous and discontinuous. Therefore, when the stripping operation is within about 10 feet of the ore horizon, great caution must be exercised to avoid loss of ore. Very thin cuts of waste are taken with the scrapers as the ore body is approached, and each cut is supervised by grade-control personnel. As the ore is exposed, it is cleaned by dozers or loaders until a large exposed lump of ore remains on the pit floor.

Mining of the ore is accomplished with a backhoe of 2 1/4 to 2 3/8 cubic yard capacity. Ore is loaded into 20- or 35-ton trucks for transport out of the pit. Mining is controlled by grade-control personnel equipped with Geiger counters which detect the gamma radioactivity associated with uranium daughter products in the mineralized ore.

Mine reclamation is playing an increasingly important role in the feasibility, planning and economics of open pit mining. State regulations and their enforcement vary from state to state.

3.2.4
Bore-Hole Mining

Bore hole mining differs from solution mining in that the ore is actually broken up in-place and removed from the bottom of the bore hole by fluid flow. Figure 3-5 depicts a hypothetical bore-hole mining arrangement. A series of bore holes is first drilled into the ore body, and then a steel pipe is used to lower a high-pressure horizontal nozzle into the hole, and water is pumped at high pressure into the ore body. The high pressure water breaks up the ore and puts it into a slurry. The slurry is


Collection Tank
Uranium Recovery Plant
Installing Bore Hole
Mining
Backfilling Mined-out Cavities

SOURCE: Adapted from Lang & Archibald, 1976

Figure 3-5
Hypothetical Bore-Hole Mining System

pumped from the bore-hole to a mill for processing via a collection tank. Tailings from the mill are pumped into the mined-out cavities in the ore body as backfill. Bore-hole mining is being tested in various mining applications but this technique is currently not in commercial use in the uranium industry.

3.3
Uranium Processing Methods

Uranium ore processing methods include:

- Conventional acid leaching
- Conventional alkaline leaching
- In-situ leaching (solution mining)
- Heap leaching
- Recovery of uranium as a byproduct

Comparison of Acid and Alkaline Leaching

Uranium is recovered from the ore by dissolution in a liquid medium, commonly called leaching. In order to increase the rate of uranium dissolution, the pH of the leaching solution is either decreased (acid) or increased (alkaline), depending on the characteristics of the ore. Acid leaching is generally more effective than alkaline leaching for treating difficult ores. Acid treatment usually requires less leaching time and lower temperatures and provides more flexibility to deal with changing ore characteristics than is possible with an alkaline process.

Also, acid leaching usually does not require grinding the ore to as fine a size as does alkaline processing. In acid circuits, however, a substantial portion of the leaching solution must be rejected to tailings after the uranium is removed because soluble impurities tend to concentrate excessively.

In contrast, alkaline leaching is more selective for uranium minerals so that leaching solutions contain fewer impurities. Because of the relatively pure solutions, direct precipitation of yellowcake often is feasible without solution purification, and leaching solutions may be regenerated and recycled with less problems due to impurity buildup. Alkaline solutions are relatively noncorrosive and are very suitable for treating high lime ores which would consume large quantities of acid.

Leaching Agent Determination

The characteristics of the ore and the relative process economics will determine the leaching reagent best suited to a particular ore. The predominant factors in this decision are reagent consumption and the maximum uranium extraction obtained with the particular leach liquor (Merritt, April 1977). Sulfuric, nitric, hydrochloric and other acids may be used for leaching, but sulfuric acid is used almost exclusively due to cost and corrosion factors. Usually, mixtures of ammonium carbonate and ammonium bicarbonate solutions are used for solution mining.

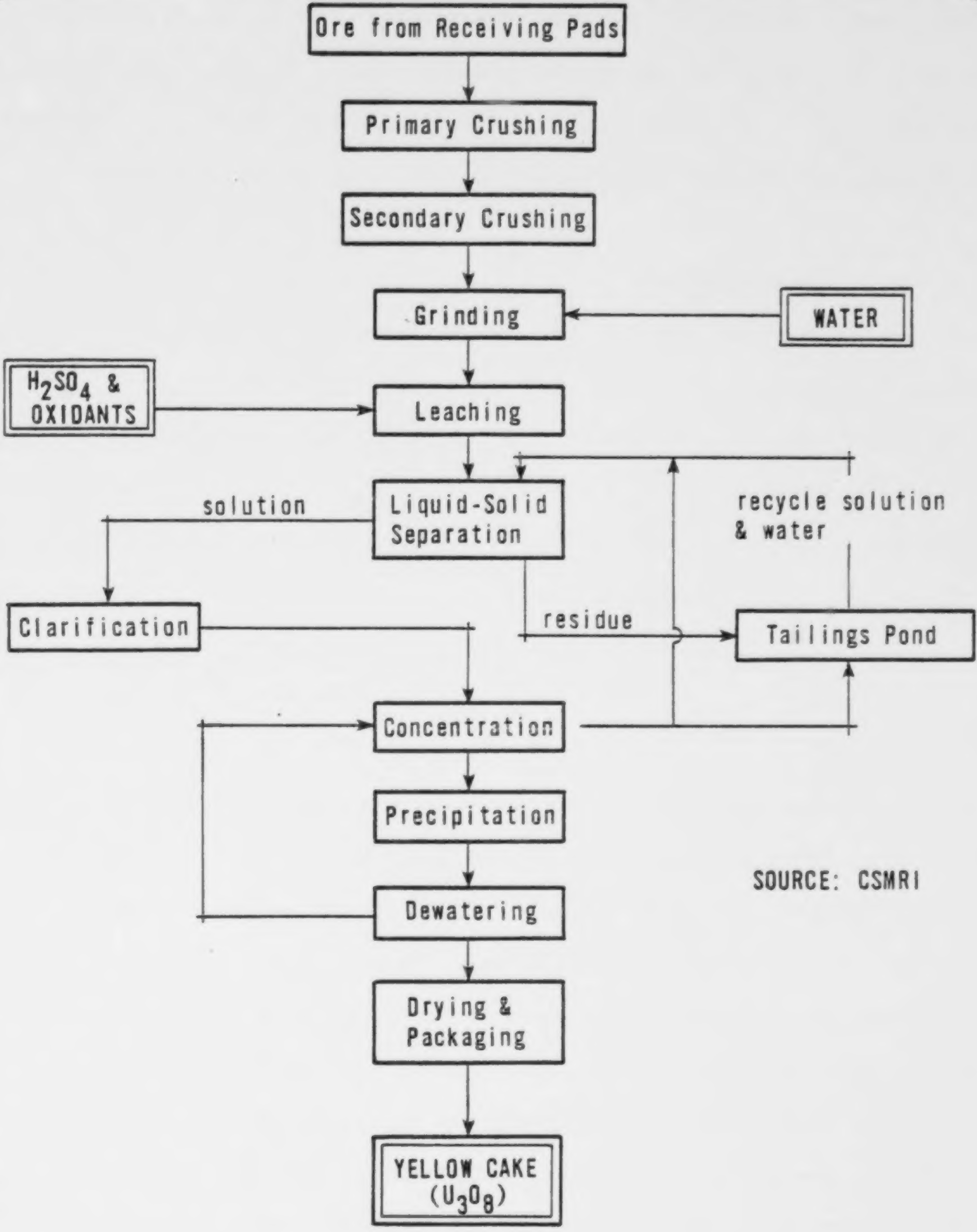
Environmental considerations may also influence lixiviant selection, especially for solution mining operations. Federal and state agencies have placed strict requirements for restoring the water in a uraniferous aquifer to its original state, and thus many solution mining operators may find it necessary to select a leaching solution based on these environmental regulations. Of particular concern with ammonium carbonate solutions is the residual ammonia level in mined aquifers.

3.3.1
Conventional Acid Leaching

The majority of the uranium ores treated in the U.S. today are processed in conventional sulfuric acid leaching mills. In its simplest form, the typical sulfuric acid mill reduces the size of the ore, leaches the ground pulp to dissolve the uranium, purifies the uranium-bearing solution and precipitates the yellowcake from the purified solution. A typical flowsheet for an acid leaching mill is shown on Figure 3-6.

Crushing and Grinding

Coarse ore is retrieved from storage pads and fed to the crushing circuit. The primary crusher reduces the size of the ore to 2 to 6 inches in diameter, while the secondary crusher further reduces the size of the ore to 1/8 to 1/2 inch. The product from the crusher circuit is fed to rod or ball mills where water is added, and the ore is ground finer to liberate the uranium minerals from waste constituents, thereby rendering the uranium minerals susceptible to chemical attack. In general, most acid leaching mills grind the ore to 28 mesh, but the size of grind may vary from 10 to 200 mesh.



Ore from Receiving Pads
Primary Crushing
Secondary Crushing
Grinding
WATER
H_2SO_4 & OXIDANTS
Leaching
Liquid-Solid Separation
solution
recycle solution & water
Clarification
residue
Tailings Pond
Concentration
Precipitation
Dewatering
Drying & Packaging
YELLOW CAKE (U_3O_8)

SOURCE: CSMRI

Figure 3-6
U_3O_8 Extraction by Sulfuric Acid Leaching

Semiautogenous Mills

A relatively recent trend is to replace mechanical secondary crushers and rod mills with semiautogenous grinding mills. The semiautogenous mills eliminate the need for fine ore storage and simplify the problems associated with wet and frozen ore. The primary crushing circuit is not necessarily an integral part of the main plant.

Leaching

From the grinding circuit, the ore slurry is pumped to the leaching circuit. Sulfuric acid and an oxidant, such as sodium chlorate, are added to the pulp to dissolve the uranium. Acid leaching is usually accomplished in mechanically agitated tanks arranged in series, but air agitated tanks (Pachucas) are also used. Leaching times vary from 4 to 30 hours, and leaching temperatures range from ambient to 90 degrees Centigrade. Acid and oxidant requirements depend on the mineralogy of the ore and the concentration of free acid required to dissolve the uranium.

Liquid-Solid Separation

The next stage in the milling process is to separate the uranium-bearing solution from the spent ore residue. Basically, the liquid-solid separation may be accomplished by countercurrent decantation (CCD) in thickeners or by separating the sand and slime fractions of the pulp followed by treating the slime portion in a CCD or resin-in-pulp (RIP) circuit.

The majority of the acid-leaching mills operating today use CCD for liquid-solid separation. In the CCD circuits, solids and washing solutions move countercurrently to each other in thickeners to achieve displacement of all but 1 percent or less of the soluble values from the solid residue. The residue is then discharged to waste while the solution advances to purification and concentration.

At some mills, the sands are separated from the slimes by cyclones and/or mechanical classifiers. Usually, this is done to prevent the coarse sand particles from overloading the thickeners. After the sand-slime split is accomplished, the slime pulp will contain over 99 percent of the soluble uranium, and the sands can therefore be discarded. The slime fraction can then be processed in a conventional CCD thickener circuit. At two mills, however, the slimes are treated in RIP circuits to recover uranium directly from the pulp. Solution from the CCD circuit is clarified or filtered to insure removal of fine, suspended solids from the uranium-bearing liquor.

Concentration

The next step involves concentration of the uranium in solution. All acid leaching mills use at least one stage of resin ion exchange (IX) or solvent extraction (SX) and in some cases both to selectively extract uranium from the leaching solution. Subsequent removal of uranium from the resin or solvent with a suitable reagent yields a purified and concentrated solution of uranium from which a high-grade uranium product can be precipitated. Solvent extraction and resin ion exchange both involve the interchange of ions between the leaching solution and either a solid resin or an organic liquid. Both techniques are multistage processes employing various types of equipment to contact the solution with the exchange media.

Resin ion exchange involves contacting the solid 20-50 mesh resin beads with uranium-bearing liquor in a series of tanks or "columns." The uranium ions are selectively adsorbed onto the resin beads and the barren solution leaving the columns can be recycled to the CCD washing circuit and/or discarded. After the resin beads are saturated with uranium, the resin is eluted with a suitable reagent, and the concentrated solution is pumped to the precipitation circuit.

RIP systems are used to recover dissolved uranium directly from slime pulp. Different types of specialized equipment and circuits are used for this purpose in which, as the name implies, the resin is suspended directly in the pulp.

The solvent extraction process involves transfer of the uranium ions in the solution to a liquid organic extractant. The organic complex formed with uranium is soluble in the organic phase and insoluble in the aqueous phase. The exchange reaction requires intimate mixing of the two phases. Subsequent separation of these immiscible phases by settling yields a top layer of the metal-enriched organic solution and a bottom layer of barren solution which is recycled to the CCD washing circuit and/or discarded. The loaded organic is then recontacted with a suitable reagent to transfer the uranium back to a concentrated aqueous solution.

A two-stage concentration process employing resin ion exchange followed by solvent extraction is termed the Eluex process. Conventional column or RIP ion exchange is used to adsorb soluble uranium. The loaded resin is eluted with sulfuric acid, and the eluate is fed to a solvent extraction circuit where uranium is extracted by an organic liquid. The loaded organic is stripped of the uranium, and the concentrated solution goes to precipitation. The Eluex process is an extremely efficient method for concentrating uranium from dilute solutions and eliminates extraneous ions (such as chlorides used during elution and stripping) from the circuit (Merritt, Oct. 1977). Also, the process decreases reagent costs and may provide a purer uranium product. The system, however, is more complicated than other concentration processes and usually requires a greater capital investment. Although the exchange resins and organics are very selective for uranium, certain impurities may interfere with IX or SX and complicate the entire concentration circuit.

Precipitation

Several techniques can be used to precipitate uranium from acid solutions; direct neutralization with a base such as ammonia is the most common. The uranium precipitate (yellowcake) is dewatered, dried and shipped to the refinery. This final product usually contains 85 percent to 95 percent U_3O_8 and a very small percentage of uranium daughters.

Strong Acid Curing

Acid leaching methods other than mechanical or air agitation have been used in the U.S. and are now used at certain foreign operations. One such method is the strong acid curing technique. This process involves agglomerating coarsely ground ore with concentrated sulfuric acid and allowing the wetted but free-flowing ore to cure at elevated temperatures in silos, rotating drums or on pads. The acid-cured material is water leached, and the dissolved uranium can be recovered by the various methods previously described. Proponents of the process claim reduced acid consumption, increased extraction, decreased reaction times and lower capital costs (Lendrum, 1974; Smith and Garrett, 1972).

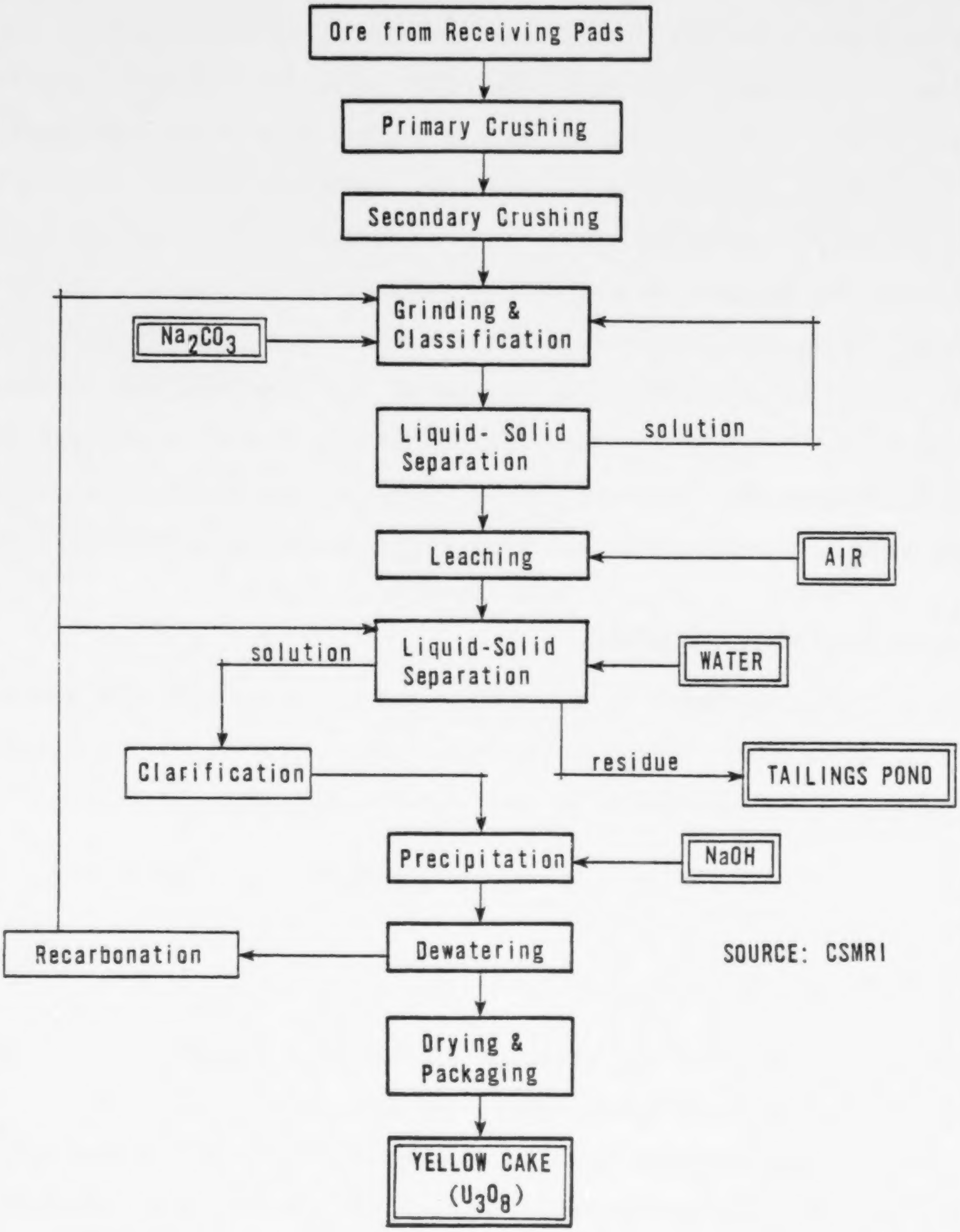
3.3.2
Conventional Alkaline Leaching

Unlike acid leaching systems, alkaline leaching requires the use of an integrated, closed-circuit process, since economics dictate recovery of the reagents in the leaching solutions.

A typical alkaline leaching flowsheet is illustrated on Figure 3-7.

Crushing and Grinding

The crushing plant for alkaline circuits is essentially the same as an acid-leaching plant except for the grinding circuit. In the alkaline-leaching process, the chemical reactions are slower and must be assisted by exposing more of the mineral surfaces. To obtain the finely-ground product, the grinding-sizing operation is usually performed at relatively low pulp densities;


Ore from Receiving Pads
Primary Crushing
Secondary Crushing
Grinding & Classification
Na_2CO_3
Liquid- Solid Separation
solution
Leaching
AIR
Liquid-Solid Separation
WATER
solution
Clarification
residue
TAILINGS POND
Precipitation
NaOH
Recarbonation
Dewatering
Drying & Packaging
YELLOW CAKE (U_3O_8)

SOURCE: CSMRI

Figure 3-7
U_3O_8 Extraction by Alkaline Leaching

therefore, a thickener or filter is used between the grinding and leaching circuits to remove the excess solution. The excess solution is recycled to the grinding circuit, and the thickened pulp (50-60 percent solids) is transferred to the leaching circuit.

Leaching

Both atmospheric and pressure leaching vessels are used in alkaline circuits, and leaching times are related to the temperature and pressure used. Pressure leaching in autoclaves may require from 4 to 20 hours at temperatures ranging from 95 to 120 degrees Centigrade and pressures varying from 30 to 90 psig. Air-agitated Pachucas are frequently used for atmospheric leaching at temperatures of 75 to 90 degrees Centigrade and leaching times of up to 96 hours. Pachucas are particularly well-suited to alkaline leaching, since the agitation air also provides the air necessary to oxidize the uranium. Since most Pachuca tanks are 40 to 60 feet deep, the benefit of approximately 25 psig at the bottom of the tanks is also realized.

Liquid-Solid Separation

The method of separating the liquids from the solids in an alkaline circuit is very similar to that used in an acid system except that filters are generally preferred because of better washing efficiency and because of the difficulties associated with achieving good densification with the finer solids and more viscous alkaline solutions.

Precipitation

Since alkaline-leaching solutions are very selective for uranium, the uranium can be precipitated directly from the clarified leach liquor, and thus the concentration step prevalent in acid leaching circuits can be eliminated. Two methods are used to precipitate uranium from alkaline liquors. If nearly quantitative recovery is required, the solutions are acidified, boiled to expel carbon dioxide and then neutralized to precipitate the uranium. However, it is usually more important to conserve the reagent for recycle than to achieve complete precipitation, and therefore the preferred method is to precipitate yellowcake with sodium hydroxide. The precipitate is dewatered, dried, packaged and shipped to the refinery (Merritt, April 1977).

The solution from the precipitation circuit is regenerated and recycled. The regeneration step involves sparging the solution with carbon dioxide in recarbonation towers to achieve the desired carbonate content. Solid sodium carbonate may also be added depending on the sodium balance throughout the circuit.

3.3.3
In-Situ Leaching (Solution Mining)

In-situ leaching is a relatively new method of extracting uranium in which wells are injected with a lixiviant and the uranium-bearing liquor is recovered. The uranium is recovered by drilling into the ore body, circulating a lixiviant to dissolve the mineral, extracting the values from the liquor and regenerating the lixiviant for continued use underground (Lewis, et al., 1976).

Advantages and Disadvantages

Increasing interest in this technique is understandable since solution mining offers several advantages compared to conventional mine-mill complexes. For ore bodies mineable by in-situ leaching, the advantages include:

- Minimal surface disturbance, particularly compared to surface mining
- Personnel exposure to radiation is significantly reduced
- Lower grade ores can be treated, effectively increasing the recoverable reserves of uranium
- Lower capital costs, improved cash flow, and generally greater return on the investment
- Less waste generation and land restoration

Major disadvantages are the potential for ground water contamination and a lower level of uranium extraction. Also, few ore bodies are suitable for in-situ leaching.

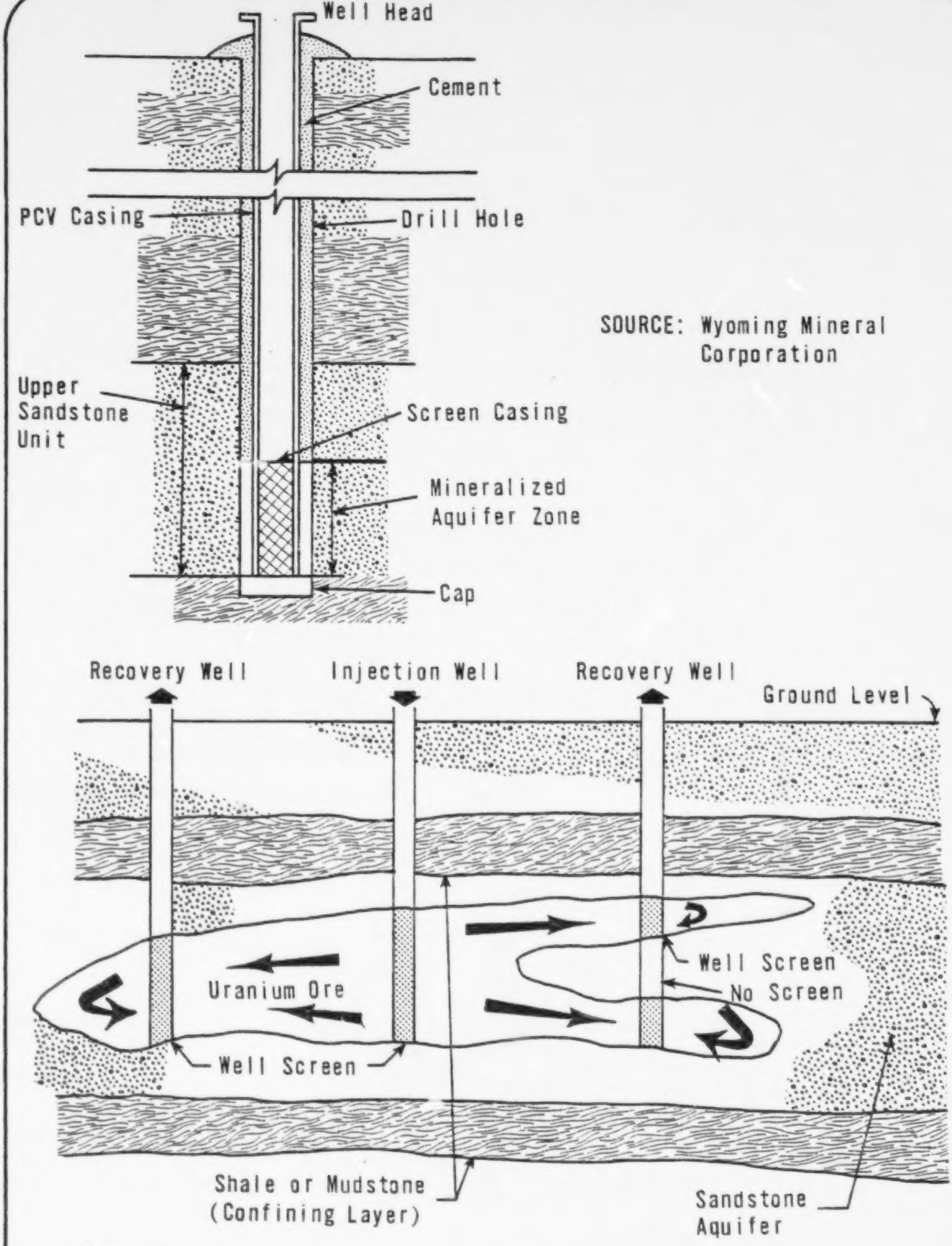
Solution Mining Criteria

For an ore body to qualify as a candidate for solution mining, the following criteria must be met (Hancock, 1977):

- The deposit should be a relatively horizontal bed underlain by impermeable strata.
- The ore body must be below the water table (i.e., a uraniferous aquifer).
- The permeability, porosity and hydrology of the deposit must be favorable.

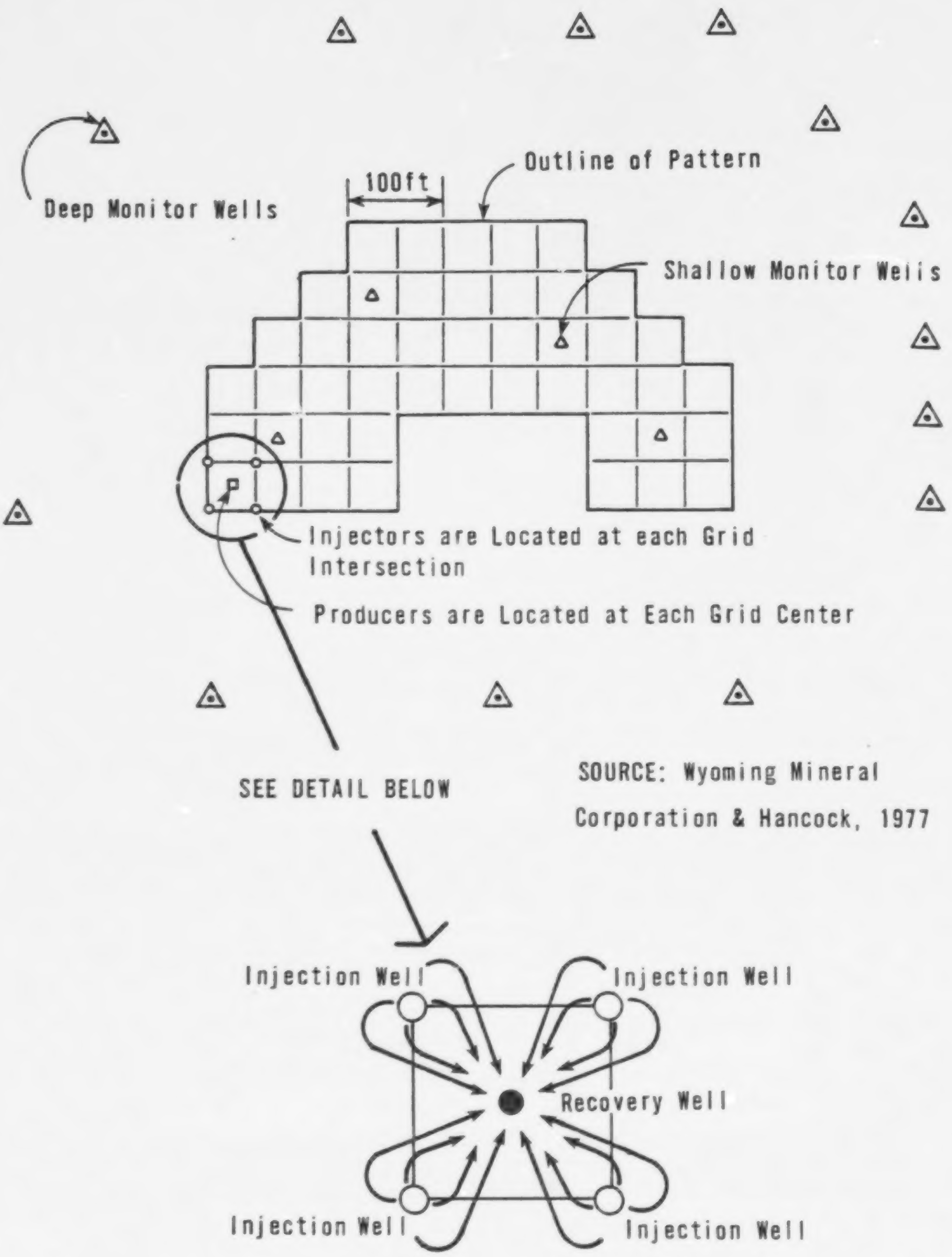
Well Field Operations

Well development is perhaps the most important aspect of solution mining. Wells for injecting the leaching solution are typically 4 inches in diameter and cased with PVC pipe cemented to the surface. Production wells are similar in construction but are usually larger in diameter. The continuous casing is interrupted where the well intersects the mineralized zone to allow introduction of a lixiviant. An example of well construction and a vertical cross section of a typical well field is shown on Figure 3-8 (Wyoming Mineral Corp., 1976). Several different types of well patterns have been investigated, but the five-spot pattern is probably the most common. A typical five-spot pattern used at U.S. Steel's property at Clay West, Texas, is shown on Figure 3-9 (White, 1975).


Well Head
Cement
PCV Casing
Drill Hole
Upper Sandstone Unit
Screen Casing
Mineralized Aquifer Zone
Cap
Recovery Well
Injection Well
Recovery Well
Ground Level
Well Screen
Uranium Ore
No Screen
Well Screen
Shale or Mudstone (Confining Layer)
Sandstone Aquifer

SOURCE: Wyoming Mineral Corporation

Figure 3-8
Well and Well-Field Design for Solution Mining


Deep Monitor Wells
100ft
Outline of Pattern
Shallow Monitor Wells
Injectors are Located at each Grid Intersection
Producers are Located at Each Grid Center
SEE DETAIL BELOW
Injection Well
Injection Well
Recovery Well
Injection Well
Injection Well

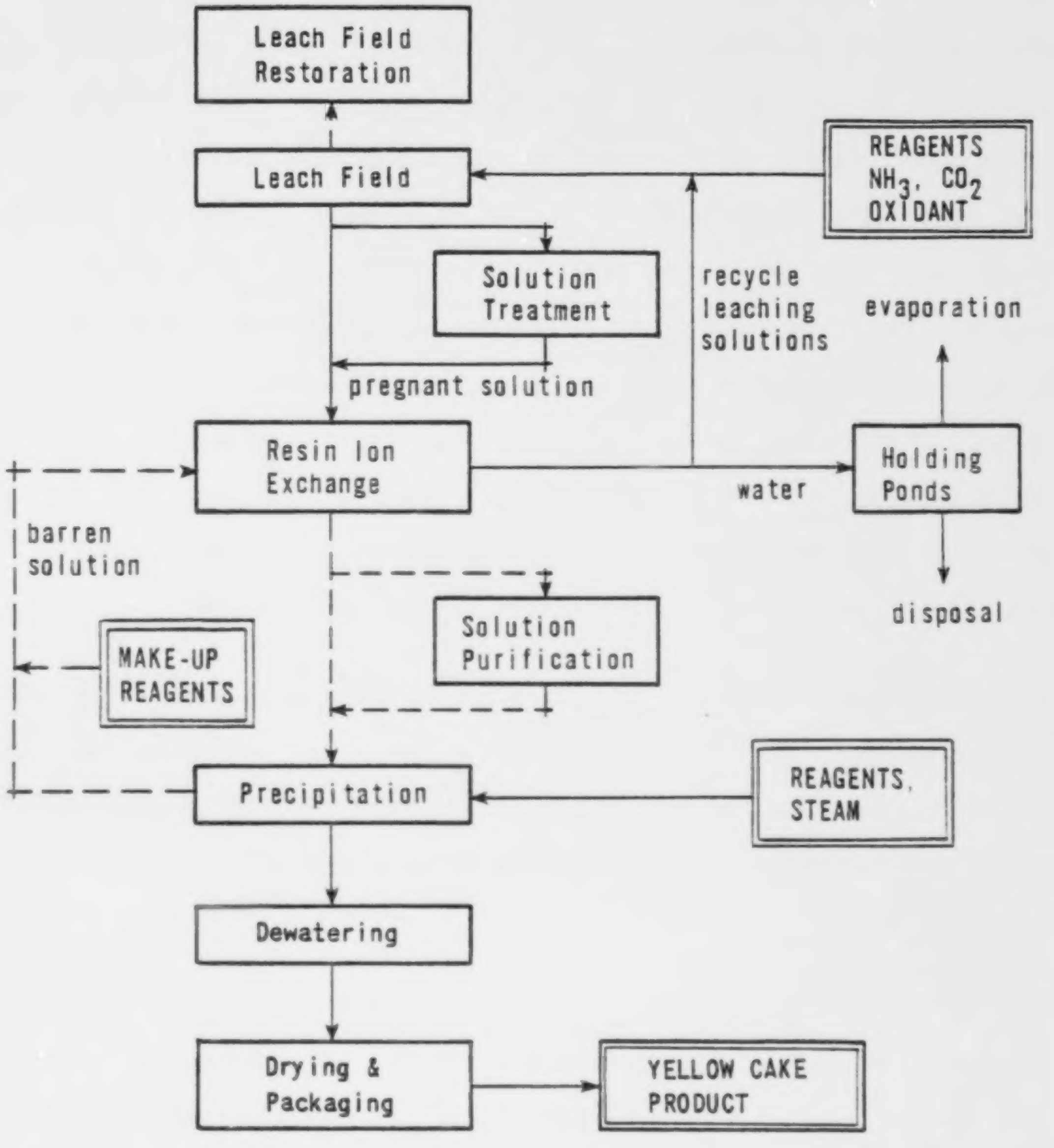
SOURCE: Wyoming Mineral Corporation & Hancock, 1977

Figure 3-9
Typical Well-Field Pattern

Injection of a lixiviant forms a hydraulic gradient within the uraniferous aquifer. This gradient, together with the withdrawal rate at the production well, determines the direction and velocity of solution flow. Solution flow is toward the production well, since the hydraulic head at that point is less than that developed at the point of injection. Thus, the pumping rates and pressures can be used to confine the lixiviant to the desired area. Normally, more liquor is withdrawn than injected to prevent solution migration and contamination of the ground water. Monitor wells are placed in the aquifer as well as outside the ore zone to detect escaping solution. If solution migration is noted, the hydraulic gradient can be adjusted by pumping to force the liquor back into the well field.

The uranium-bearing liquor is collected from the recovery wells and pumped to the plant area. The liquor is usually clarified and then treated in ion exchange columns to remove the uranium. A typical flowsheet for a solution mining operation is shown on Figure 3-10.

Although several types of leaching solutions can be used to extract the uranium, relatively weak solutions of ammonium bicarbonate or carbonate are used at most operations. Unlike conventional milling, the choice of reagent for in-situ leaching is based primarily on underground performance, including factors such as selectivity, maintenance of permeability, suitability to recirculation and environmental considerations.


Leach Field Restoration
Leach Field
REAGENTS NH3, CO2 OXIDANT
Solution Treatment
recycle leaching solutions
evaporation
pregnant solution
Resin Ion Exchange
water
Holding Ponds
barren solution
disposal
Solution Purification
MAKE-UP REAGENTS
Precipitation
REAGENTS, STEAM
Dewatering
Drying & Packaging
YELLOW CAKE PRODUCT

SOURCE: CSMRI

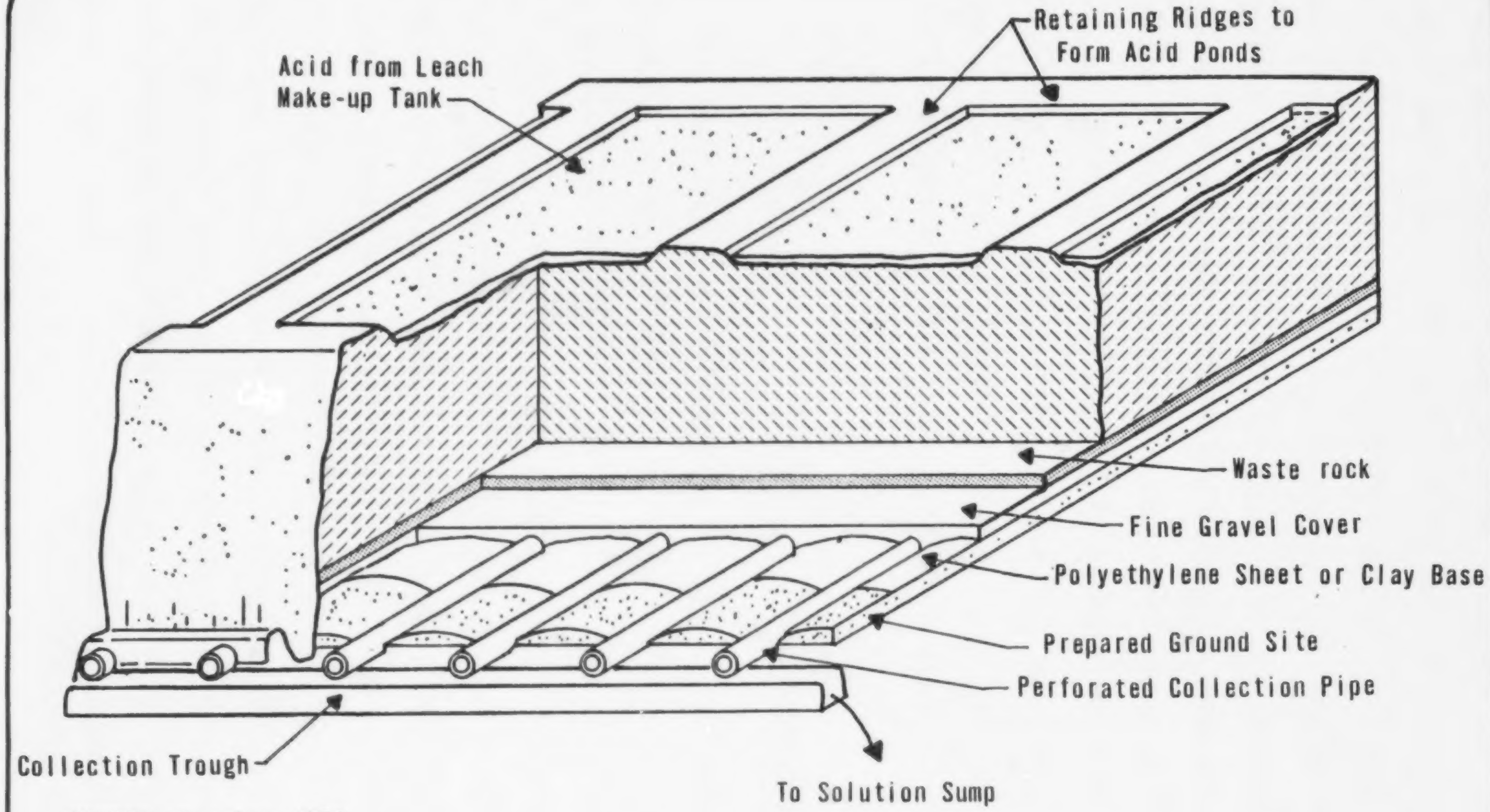
Figure 3-10
U_3O_8 Extraction by Solution Mining

3.3.4
Heap Leaching

Heap leaching is broadly defined as leaching of an ore in a static or semistatic condition either by gravity flow downward through an open pile or by flooding a confined ore pile. Heap leaching is useful for the treatment of low-grade dumps, small ore bodies located at considerable distances from the processing facilities, ores that otherwise would have been treated as waste material or, in some cases, abandoned mill tailings. The major disadvantage of heap leaching is that uranium recovery is lower than for conventional milling processes. Not all of the ore in the sloping sides of the heap is contacted by the leaching solution, and therefore uranium in the unwetted zone is not recovered.

Heap Leach Pad Construction

Typically, leaching pads are prepared by leveling a site and covering it with an impermeable liner such as plastic sheeting or a clay base (Woolery et al., 1977). The pad is constructed with a slight slope, and pipes are placed at intervals to collect the solution. The entire pad is then covered with gravel to improve drainage, and the ore is placed on the pad and leveled. Usually, berms are constructed around the ore pile to permit ponding of the leaching solutions. The actual size and configuration of a heap may vary, but a typical construction for heap leaching is illustrated on Figure 3-11 (Merritt, 1971). The solution flows downward through the ore, into the pipes, and is collected in launders. Weak sulfuric acid solutions are used, and several


Retaining Ridges to Form Acid Ponds
Acid from Leach Make-up Tank
Waste rock
Fine Gravel Cover
Polyethylene Sheet or Clay Base
Prepared Ground Site
Perforated Collection Pipe
Collection Trough
To Solution Sump

SOURCE: Merritt, 1971

Figure 3-11
Typical Construction for Heap Leaching

months may be required to complete the leaching cycle.

Uranium Recovery Options

Uranium can be recovered from the solution by the methods previously discussed--IX, SX, or Eluex. At Western Nuclear's heap leaching operation in Wyoming, which is not operating at this time, high-grade solution was shipped to the nearby mill for uranium recovery while low-grade solutions were processed through a small SX circuit at the site. Yellowcake was precipitated at the site but transported to the mill for subsequent drying and packaging. At Union Carbide's heap leaching operation at Maybell, Colorado, the uranium is concentrated by IX and precipitated at the site, but the yellowcake product is shipped to Union Carbide's Uravan, Colorado, plant for further processing. Ranchers Exploration and Development Company recently initiated a heap leaching operation near Naturita, Colorado. The operation is unique in that previously abandoned uranium mill tailings are being reprocessed. In this case, the tailings are being moved for processing from a river flood plain to a more desirable disposal site.

As with solution mining, the costly grinding and liquid-solid separation steps associated with conventional milling are eliminated. However, the ore must be mined and usually must be crushed to some extent and stockpiled to facilitate leaching. Leaching in heaps or in-situ requires several months for maximum uranium extraction in contrast to leaching times of a few hours in the majority of conventional mills. Also, recovery from a heap or solution mining operation rarely exceeds 60 to 70 percent, while recoveries in excess of 90 percent are common at conventional mills. No one processing method is right for a particular ore body--each case must be treated separately and a method selected based on the characteristics of the ore and the process economics.

Byproducts

The description of the various processing methods was simplified somewhat in that certain impurities in the uranium ore can complicate the milling flowsheet, as will the recovery of byproducts. Vanadium, copper and molybdenum are notable byproducts of uranium mills.

3.3.5
Other Methods

Most of the uranium concentrates produced in the U.S. each year are processed by the methods described. Treatment of other types of ores, however, often yields uranium as a byproduct. Phosphate and copper ores are notable examples. These ores and resultant waste streams may require consideration as radioactive materials.

Uranium Byproduct of Phosphate Concentrate

It has been estimated that the minable reserves of phosphate rock in the U.S. contain more than one billion pounds of uranium. Since the uranium content of the phosphate rock is 50 to 200 ppm, conventional leaching methods have not been effective in selectively extracting the uranium. However, an increasing amount of phosphate concentrates are being converted to phosphoric acid, and sulfuric acid used to digest the phosphate concentrates also dissolves any contained uranium. A number of uranium recovery methods are being studied. The most successful method developed thus far is a complex solvent extraction technique for recovering the dissolved uranium from the impure phosphoric acid. Uranium Recovery Corporation has been operating a commerical facility near Bartow, Florida, for several years, and Gardinier Incorporated is proceeding with construction of a similar plant near Tampa. Other companies with processes in various stages of development include Earth Sciences, Incorporated, Gulf Oil Chemicals, and Freeport Minerals (Ross, 1975).

Uranium Byproduct of Copper Leaching

Heap leaching of copper ores is practiced throughout the western United States. In this process U_3O_8, if present, is also extracted, and leach liquors at many operations contain from 1 to 40 ppm U_3O_8. Resin ion exchange can be used to recover the uranium. At the present time, Wyoming Mineral Corporation's Eluex plant at Kennecott's Bingham Canyon property is the only commercial facility extracting U_3O_8 from copper leaching solutions. Anamax is operating a similar pilot plant at their copper mine south of Tucson, and several other companies are evaluating this source of uranium (Brooke, 1976).

3.3.6
Processing Methods at U.S. Uranium Mills

The mining and processing methods used at domestic uranium mills are outlined in Table 3-2A. Proposed facilities have been listed

Plant	Mining Method	Leaching Method	Liquid-Solid Separation	Concentration	Precipitation
	Operational				
Anaconda Co., Grants, New Mexico	O.P. + U.G.	Acid	CCD	SX	NH_3
Atlas Corp., Moab, Utah	U.G.	Acid	CCD + Filt.	SX	H_2O_2
	U.G.	Alkaline (Na)	Filt.	None	$NaOH-H_2O_2$
Conoco & Pioneer Nuclear, Falls City, Texas	O.P.	Acid	CCD	SX	NH_3
Cotter Corp., Canon City, Colorado	U.G.	Alkaline (Na)	CCD + Filt.	None	NaOH
		Acid-Pressure	CCD	SX	NH_3
Dawn Mining Co., Ford, Washington	O.P.	Acid	CCD	IX	NH_3
Exxon, U.S.A., Powder River Basin, Wyoming	O.P. + U.G.	Acid	CCD	SX	NH_3
Federal American Partners, Gas Hills, Wyoming	U.G. + O.P.	Acid	SS	RIP + SX	NH_3
Intercontinental Energy Corp., Pawnee, Texas	In Situ	Alkaline (NH_3)	None	IX	Steam
Kerr McGee Nuclear Corp., Grants, New Mexico	U.G.	Acid	SS	SX	NH_3
Lucky Mc Uranium Corp., Gas Hills, Wyoming	O.P.	Acid	CCD	Eluex	NH_3
Lucky Mc Uranium Corp., Shirley Basin, Wyoming	O.P.	Acid	SS	SX	NH_3
Mobil Oil Co., Bruni, Texas	In Situ	Alkaline (NH_3)	None	IX	Steam
Rio Algom Corp., La Sal, Utah	U.G.	Alkaline (Na)	Filt.	None	NaOH
Rocky Mountain Energy, Powder River Basin, Wyoming	O.P.	Acid	CCD	SX	NH_3
Ranchers Exploration, Naturita, Colorado	None	Acid Heap Cure	None	SX	NH_3
Sohio-Reserve, Cebolleta, New Mexico	U.G. + O.P.	Acid	CCD	SX	NH_3
Union Carbide Corp., Uravan, Colorado	U.G.	Acid	CCD	IX	NH_3
Union Carbide Corp., Gas Hills, Wyoming	O.P.	Acid	SS	RIP + SX	NH_3
	O.P.	Acid Heap	None	--- Solution to Main Mill ---	
Union Carbide Corp., Maybell, Colorado	O.P.	Acid Heap	None	IX	--
Union Carbide Corp., Kingsville, Texas	In Situ	Alkaline (NH_3)	None	IX	--
United Nuclear Corp., Church Rock, New Mexico	U.G.	Acid	CCD	SX	NH_3
United Nuclear - Homestake Partners, Grants, New Mexico	U.G.	Alkaline (Na)	Filt.	None	NaOH
U.S. Steel, George West, Texas	In Situ	Alkaline (NH_3)	None	IX	--
U.S. Steel - Niagra Mohawk, George West, Texas	In Situ	Alkaline (NH_3)	None	IX	--
Uranium Recovery Corp., Mulberry, Florida	None	None	None	--- SX from Phosphoric ---	
Western Nuclear, Inc., Jeffrey City, Wyoming	U.G.	Acid	SS	RIP + SX	NH_3
Wyoming Mineral Corp., Bruni, Texas	In Situ	Alkaline (NH_3)	None	IX	--
Wyoming Mineral Corp., Ray Point, Texas	In Situ	Alkaline (NH_3)	None	IX	--
Wyoming Mineral Corp., Bingham Canyon, Utah	None	None	None	-- Eluex from Cu Solutions--	

SOURCE: CSMRI

Key to Table:
O.P. = Open Pit
U.G. = Underground
CCD = Countercurrent Decantation in Thickeners
SS = Sand Slime Separation
Filt. = Filters
IX = Column Ion Exchange
SX = Solvent Extraction
RIP = Resin in Pulp

Table 3-2A
Process Variations at Operational U.S. Uranium Mines and Mills

in Table 3-2B and are in various stages of development (White, 1975; Facer, 1977; Reed et al., 1976).

3.3.7

Future Trends in Yellowcake Production

In 1975, 23 open-pit mines produced 55 percent of the uranium ore while approximately 42 percent of the tonnage came from 121 underground mines. The balance of production was attributed to heap leaching operations, solution mining, uranium recovered from mine waters and phosphoric acid, and miscellaneous low-grade stockpiles. In 1974, the percentage of ore mined from open pits was 58 percent and 40 percent from underground mines (Prast, 1976; Gordon, 1976). However, it is difficult to predict trends with any reasonable degree of accuracy. New discoveries in New Mexico are deep and will therefore be exploited by underground mining methods. In contrast, several large, shallow, low-grade deposits are being investigated elsewhere, and economic development of these ore bodies will require mining large tonnages from open pits.

New plants are not likely to differ significantly from existing plants. Recent improvements in filtration, ion exchange, and thickening technology will alter the type of equipment used, but the basic processing methods will remain the same. However, exploitation of small, low-grade deposits by solution mining, and heap or vat leaching will receive increased attention. Portable skid-mounted plants may be used in many cases or crude concentrates and solutions may be shipped to mills located some distance away from the field operation. Also, beneficiation

Plant	Mining Method	Leaching Method	Liquid-Solid Separation	Concentration	Precipitation
	Proposed				
Chevron Oil, Panna Maria, Texas	O.P.	Acid	--	--	--
Cleveland Cliffs Iron Co., Pumpkin Buttes, Wyoming	In Situ	Alkaline (NH_3)	None	IX	Steam
Conoco, Crownpoint, New Mexico	U.G.	Acid	SS or CCD	SX	NH_3
Energy Fuels, Blanding, Utah	Ore Buying	Unannounced			
Gulf Mineral Resources, McKinley County, New Mexico	U.G.	Acid	CCD	SX	NH_3
Homestake Mining Co., Gunnison, Colorado	O.P.	Alkaline (Na)	Filt.	None	NaOH
Mobil Oil Co., Crownpoint, New Mexico	U.G.	Acid	CCD	SX	NH_3
Ogle Petroleum, Bison Basin, Wyoming	*In Situ*	Alkaline (NH_3)	None	IX	Steam
Petrotomics, Shirley Basin, Wyoming	O.P.	Acid	CCD	SX	NH_3
Phillipps Petroleum, McKinley County, New Mexico	U.G.	Acid	CCD	SX	NH_3
Pioneer Nuclear, Inc., McKinley County, New Mexico	U.G.	Unannounced			
Pioneer-Uravan, Uravan, Colorado	U.G. + O.P.	Acid	Unannounced		
Plateau Resources, Ltd., Hanksville, Utah	U.G.	Acid	CCD	SX	NH_3
Rocky Mountain Energy, Casper, Wyoming	In Situ	Acid	None	IX	--
TVA, Edgemont, South Dakota	O.P.	Acid	Unannounced		
Union Oil, Shirley Basin, Wyoming	O.P.	Acid	CCD	SX	NH_3
United Nuclear Corp., Morton Ranch, Wyoming	U.G. + O.P.	Acid	CCD	SX	NH_3
Western Nuclear, Inc., Ford, Washington	O.P.	Acid	CCD	SX	NH_3
Wyoming Minerals Corp., Irigrary Site, Wyoming	In Situ	Alkaline (NH_3)	None	IX	--
Gardinier Inc., Tampa, Florida	None	None	None	SX from Phosphoric	
Cyprus Mines Corp., Canon City, Colorado	O.P. + U.G.	Acid	Unannounced		
Freeport Minerals, Uncle Sam, Louisianna	None	None	None	SX from Phosphoric	
Texara Corp., Hobson, Texas	In Situ	Alkaline (NH_3)	Unannounced		
Solution Engineering, Three Rivers, Texas	Recovery from Tailings	Liquor	None	IX	--
Phelps Dodge, Bisbee, Arizona	None	None	None	Eluex from Cu Solutions	
Anamax, Tucson, Arizona	None	None	None	Eluex from Cu Solutions	
Kerr McGee Nuclear Corp., Casper, Wyoming	O.P. + U.G.	--	Unannounced		

SOURCE: CSMRI

Key to Table:
O.P. = Open Pit
U.G. = Underground
CCD = Countercurrent Decantation in Thickeners
SS = Sand Slime Separation
Filt. = Filters
IX = Column Ion Exchange
SX = Solvent Extraction
RIP = Resin in Pulp

Table 3-2B
Process Variations Proposed for Future U.S. Uranium Mines and Mills

methods and ore buying stations may increase. Experience has shown that some ore buying stations may also become mill sites when sufficient ore supplies are assured through exploration and mining in nearby areas.

Beneficiation

For the few ores exhibiting suitable beneficiation characteristics, effective methods have included sizing, radioactive sorting and froth flotation to generate uranium-rich concentrates. However, beneficiation methods rarely yield tailings low enough in uranium to justify the economic loss as compared to processing all of the ore in a mill. The most successful applications of beneficiation techniques have not been for direct concentration of the uranium, but for separation of the ore into fractions, such as high and low lime and carbon or sulfide fractions, which can be treated more efficiently by specific leaching methods. Nevertheless, beneficiation methods will receive increased attention as lower and lower grade ores are developed.

Ore Buying Stations

Certain corporations buy ore from several independent miners in a given area. The individual lots of ore are processed through a centrally located sampling plant to determine the uranium content of the ore lot and expedite settlement payments. The primary crushing is accomplished at the sampling plant, and the crushed ore is then shipped to the mill, which may be located some distance from the sampling plant. Examples of ore buying stations include the four sampling plants located at Blanding, and Hanksville, Utah (operated by Energy Fuels and Plateau Resources, Ltd.) and two plants located near Naturita and Whitewater, Colorado (General Electric Corp. and Cotter Corp.).

3.4
Production Costs

Uranium production costs vary substantially with the location of the deposit, stripping ratios, ore grade, mill capacity, reagent consumption and many other factors. Resource requirements and capital and operating costs for a mine/mill complex are presented in the following section.

3.4.1
Resource Requirements

In addition to the availability of an ore supply, important considerations in evaluating a potential site for a uranium mill are the availability of labor, utilities, land, services and sources of required supplies in the area. Significant resource requirements for uranium complexes are:

- LABOR - Total employment in the uranium industry in 1975 was approximately 9,700, 2,100 in exploration, 5,400 in mining and 2,200 in milling. Of the 5,400 individuals associated with mining, 1,800 were employed as underground miners, 700 as open-pit miners and 1,200 as supervisors and administrators.

  A typical 2,000 tpd open-pit conventional acid-leaching operation (CCD, SX NH_3 precipitation) employs approximately 200 people. Of the 200, approximately 65 would be employed in the mill, 90-100 in the mine and the remainder in administration and nonprocess functions. However, labor requirements vary greatly and may be as high as 400-450 people (Goodier, 1978). A total of about

230 people would be employed during the peak construction phase of such a facility. For comparison, a typical 1,000 tpd underground mine would require approximately the same labor force for mining as a 2,000 tpd open-pit operation.

- UTILITIES - Requirements for utilities vary substantially in the industry, but the range for uranium mills is approximately (Merritt 1971):

Utility	Quantity/Ton Ore
Electricity	17 to 35 kw hr
Fuel	348,000 to 1,120,000 Btu
Water	1 to 7 tons
Steam	179, to 800 lbs
Compressed Air	1,000 to 13,000 ft^3

Most of the power required by uranium mills is for crusning and grinding, and the wide range is due to variations in ore hardness and fineness of grind required. Variations in fuel requirements are due to different temperatures employed during leaching, the amount of building heat required, and the availability of by-product steam from various sources such as acid plants. Most of the variations in water and air requirements are due to the process employed.

Utility requirements for mines also vary substantially. Power requirements for a 1,000 tpd underground mine were recently reported at approximately 22 kw hr/ton. Of this value, 50 percent was for ventilation. Water consumption at the same mine was reported at 1,000 gpd (Harvey 1977).

Utility requirements for open-pit mines are considerably different than those for underground mines. Electrical power requirements are minimal, 2 kw hr per ton of ore; principal applications are pit dewatering and lighting. Water requirements are normally greater in open-pit mines with dust abatement the major use. Consumption could approach 50,000 gpd, although much of this could be obtained from the pit itself. Fuel consumption for mobile machinery represents the major utility requirement in surface mining. Fuel consumption typically runs from 10 to 40 gal of diesel fuel per machine per hour (Goodier, 1978). Mines using electric-powered equipment would consume more electricity and less fuel. Depending on quantities of overburden moved to recover the ore, fuel requirements could range from 2 gal per ton.

- SUPPLIES - A large portion of the supplies necessary to sustain an operation are the chemicals used in the milling operation. It is not possible to generalize chemical requirements, since the amounts will vary widely with the type and amount of ore being processed. Acid requirements

SUPPLIES, Continued

can vary from 40 lb/ton for an easily treated Wyoming ore and 300-500 lb/ton for a refractory ore from the western slope of Colorado. For alkaline circuits, sodium carbonate consumption can vary from 10 to 80 lb/ton of ore. Similary, oxidant requirements for an acid circuit can vary from 0 to 40 lb of sodium chlorate per ton of ore treated. Flocculating agents are used to aid the liquid-solid separation process. Typical requirements are 0.1 lb/ton of ore. Ammonia requirements for yellowcake precipitation are typically 0.4 lb/lb of U_3O_8. Other chemicals which are used in a typical acid circuit include lime, kerosene and amine organic extractant. Blasting explosives also contribute significantly to supply requirements.

- LAND - Surface land requirements are directly related to the type of mining method used and the tonnage of ore processed. A 5,000 tpd open-pit operation with a 30:1 stripping ratio will cover more surface area than a 1,000 tpd underground operation. The mine is the greatest land consumer, followed by the tailings pond, and then the surface works. Several thousand acres may be involved in a surface mining operation, and the workings of an underground mine can cover as much area, although it is not visible. Typical land requirements for the mill and other surface works range from 10 to 20 acres.

- MAJOR MINE EQUIPMENT - Machinery requirements for a 1,000 tpd underground and open-pit mine are compared below:

Underground

14 long hole drills
3 Wagner trucks
11 tractor-trailer units
1 single-boom jumbo
1 road grader
1 compressor 2,400 cfm
1 compressor 1,200 cfm
1 fan
1 hoist

Open-pit

3 shovels, 16 yd^3 electric
2 rotary blast hole drills
2 hydraulic backhoes, 3 yd^3
16 haulage trucks, 120 ton
9 haulage trucks, 35 ton
2 wheel loaders
7 push-pull scrapers
4 crawler tractors
2 wheel tractors
3 motor graders

The equipment fleet for the open-pit operation includes the equipment needed for pre-production stripping.

- SUPPORT FACILITIES - In addition to the mine, the mill and the tailings pond, additional on-site facilities are required to service the operation. Support facilities which are common to all processing complexes include a warehouse, a mill maintenance shop, a repair and service garage for the mine mobile equipment, an analytical and metallurgical laboratory, a changehouse and an administration building. Smaller, additional buildings are required for the scale house, fire truck garage, lubrication oil storage, flammable liquids storage, tailings water pumphouse, and tire storage.

Other on-site and off-site facilities may be necessary to support the operation. Facilities which may be included in this category include an acid plant and a town site. Western Nuclear's operation at Jeffery City, Wyoming, represents a good example of an uranium operation with a town site.

3.4.2
Capital and Operating Costs

Although the price of U_3O_8 for immediate delivery has risen from $5.95/lb in August 1971 to greater than $40/lb today (Nucleonics Week, March 16, 1978), the average contract price for U_3O_8 is approximately $14/lb. Since many uranium producers have been in operation since the early 1950's, the plants and all of or a major portion of the mine development costs have been amortized. For these reasons, these producers can continue to produce relatively low-cost yellowcake.

In contrast, the newcomer to the industry must absorb the inflation which has occurred since the 1950's and must, therefore, demand a higher price for the product. Since 1973, average mining labor costs have increased from approximately $4.50/hr to $8/hr. The cost of drilling rigs capable of 1,000-foot depths has increased from $22/hr in 1970 to about $65/hr in 1978 (Butts, 1978). Also, the cost of No. 2 diesel fuel has risen over 350 percent in the past six years (Koch, 1977). These are but a few examples of the inflationary trends affecting the industry. For these and other reasons, a new producer in 1978 must receive \$25 to \$30/lb of U_3O_8 to break even (recover capital and operating costs). This break-even value excludes the cost of exploring for new reserves.

Due to the many possible combinations of mining and processing methods, it is difficult to present cost generalizations. However the capital expenditure required to develop a 1,000-foot-deep ore body by underground mining methods is roughly \$80 to \$120 (1978 dollars) per annual ton of ore recovered. A 2,000-foot-deep deposit could require capital investment of as much as \$200 per annual ton. The capital cost of a surface mine can equal the capital costs of the underground mine. This situation is due to the extensive pre-production stripping required to expose the ore body. Mill capital costs are presently about \$15,000 per daily ton of capacity (1978 dollars), assuming a conventional acid-leaching, CCD and SX circuit is utilized.

Example Costs for Open-pit Mine and Mill

Typical capital and operating costs for a new conventional 1,000 tpd open-pit mine and mill facility are summarized in Table 3-3 (Phillips, 1977). The costs are based on milling 1,000 tpd of ore containing 0.10 percent U_3O_8 with a stripping ratio of 22 cu yd/pound of U_3O_8. Truck shovel combinations and scrapers are used for stripping, and one-third of the stripping costs are treated as pre-stripping. Trucks and front end loaders or

Operating Costs	$/ton Ore	$/lb U_3O_8
Strip and Internal Waste	20.00	11.11
Mining	3.80	2.11
Milling	7.00	3.89
General and Administrative	3.00	1.67
Aquifer Restoration	0.80	0.44
Royalty and Severance Taxes	3.60	2.00
Total	$38.20	$21.22

Investment	$ Million
Mine Mobile Equipment	9.0
Mill and Tailings	15.0
Mine Shops and Electric	2.5
Roads, Site Preparation, etc.	1.0
Total Capital	$27.5
Working Capital	3.0
Pre-stripping	7.0
Infrastructure	4.0
Total Initial Investment	$41.5

SOURCE: Adapted from Phillips, April 1977.

Table 3-3

Economics of Conventional Mining and Milling

backhoes are used for mining and an internal waste ratio of three cu yd/ton of ore was assumed. Milling costs were based on a conventional agitated acid leaching, solvent extraction, and precipitation circuit. Acid consumption was assumed at 60 lb/ton of ore, and overall recovery was estimated at 90 percent. General and administrative expenses include on-site supervision, office and safety personnel, and home office overhead allocation. Royalties and severance taxes were estimated at 2 percent and 3 percent of gross revenue. Working capital allows for three months of operation, and infrastructure including relocation and training expenses, housing subsidies and pre-startup admininstrative expenses. A 24-month construction period was assumed, and the life of the property was estimated at 12 years.

Estimated Costs for In-Situ Leaching

The estimated capital and operating costs for in-situ leaching of a 0.05 percent U_3O_8 ore body are shown in Table 3-4. The estimate was based on a production rate of 250,000 lb U_3O_8/yr from a 500-foot-deep deposit. The wells are drilled in a line-drive pattern, and the number of production and injection wells are equal. The injection and production wells are constructed identically to allow reversal of functions, and each well is 5 inches in diameter, cased with PVC and cemented to the surface. The wells are spaced at 50 feet, and the injection rate was assumed at 10 gpm per well. Well costs were increased by 5 percent for failures.

The estimate was based on a sulfuric acid rather than ammonium

Operating Costs	$/lb U_3O_8
Wells	12.10
Pumps and Piping	2.32
Power, Coring, etc.	0.86
Milling	6.76
General and Administrative	1.40
Reclamation	0.34
Royalty and Taxes	2.00
Total	$25.78

Investment	$ Million
Mobile Equipment	2.3
Mill and Tailings	6.5
Roads, Site Preparation, etc.	1.0
Total Capital	9.8
Working Capital	1.4
Initial Well Field	2.2
Infrastructure	1.3
Total Investment	$14.7

SOURCE: Adapted from Phillips, 1977.

Table 3-4
Economics of Solution Mining

carbonate leaching, but the costs should not vary significantly. Mild steel would replace FRP tanks for a savings, but most other costs would remain essentially the same. The uranium-bearing liquor contains approximately 50 ppm U_3O_8 and is processed in ion exchange columns followed by solvent extraction. Calcined yellowcake is the final product. Overall recovery was estimated at 60 percent for the solution mining operation. Design and construction of the in-situ complex was assumed to require 18 months, and the productive life of the deposit was assumed at 12 years to match the open-pit model.

The reported values are presented to acquaint the reader with general uranium production costs. These cost figures should not be used to project the economics associated with any existing or proposed facilities, since estimates vary greatly and depend on many project specific conditions. For example, the Wyoming Department of Economic Planning and Development estimates the operating cost of a uranium mill to be $10 per ton of ore (Goodier, 1978). However, certain uranium mill operators have recently reported that total process chemical costs alone approach $16 per ton of ore treated (Butts, 1978).

3.5
Mill Tailings Management

Mill tailings, as discussed herein, are defined as gangue and other refuse material resulting from the washing, concentration and treatment of ground ores. Their disposal is a critical part of the uranium milling process. In view of the long half lives of the radionuclides in tailings, the integrity of related containment structures must be assured for many millennia, which for planning purposes can be considered perpetuity.

Historically, in the mining industry, some practices have resulted in unsafe structures, and disastrous failures have occurred. The problem is complex. An interdisciplinary technical approach is required for safe and efficient construction and operation. However, it is possible with today's earth dam design practices to build safe, permanent structures.

Concerns related to environmental impacts add an additional dimension to uranium mill tailings management. Post-operational reclamation and maintenance are important regulatory concerns in preventing radioactive contamination of the environment and exposure of the population to radiation.

3.5.1
Performance Objectives

The following performance objectives for management of tailings from uranium ore processing plants were issued for industry guidance by the Nuclear Regulatory Commission (NRC Branch Position, May 13, 1977).

Siting and Design

1 Locate the tailings isolation area remote from people such that population exposures are reduced to the maximum extent reasonably achievable.

SITING AND DESIGN, Continued

2 Locate the tailings isolation area such that disruption and dispersion by natural forces is eliminated or reduced to the maximum extent reasonably achievable.

3 Design the isolation area such that seepage of toxic materials into the ground water system is eliminated or reduced to the maximum extent reasonably achievable.

During Operations

4 Eliminate the blowing of tailings to unrestricted areas during normal operating conditions.

Post-Reclamation

5 Reduce direct gamma radiation from the impoundment area to essentially background.

6 Reduce the radon emanation rate from the impoundment area to about twice the emanation rate in the surrounding environs.

7 Eliminate the need for an ongoing monitoring and maintenance program following successful reclamation.

8 Provide surety arrangements to ensure that sufficient funds are available to complete the full reclamation plan.

3.5.2
Site Selection for Tailings Impoundments

Factors which must be considered when evaluating the suitability of candidate sites for tailings disposal include economics, engineering feasibility, safety and environmental impact. Environmental considerations are discussed in Chapter 4. Site-specific factors are discussed below.

Location of Ore Processing Facility

Suitable locations for tailings disposal have an important influence on the selection of candidate sites for the ore processing facility. The location of suitable disposal sites may, in fact, limit siting options. The location of the mill is also influenced by the mine location and other factors, such as population centers, transportation and availability of services. Accordingly, although certain physical conditions are required for a suitable tailings disposal site, the final selection must be made in conjunction with economic and engineering studies which take into account siting of all elements of the mining and processing facilities.

Topography

A natural depression offers the most economical and, in most cases, the safest structure for impoundment of tailings, but such disposal sites are rare. Dams across valleys or on side hills must take into account storm runoff waters and provide measures to prevent erosion. A stock-pile type of dam on relatively level ground can eliminate the damage from runoff water.

Engineering Geology

Thorough geotechnical investigations of a potential site must be made. Subsurface investigations must assess the characteristics of foundations and abutments with respect to seepage and stability when subjected to the loadings of the retaining structures. Geotechnical design parameters for all materials to be utilized in the retention embankment and its foundation must be defined. Discussions of necessary geotechnical are presented in NRC Regulatory Guide 3.11, and in Colorado Geological Survey Guidelines, March 8, 1978.

Seismic Activity

The potential site for tailings impoundment may be subjected to the effects of seismic activity. Application of modern earth-dam practices can result in safe impounding structures even in zones of high seismic activity.

Meteorology

Meteorology is important for site evaluation. Site meteorological data and dispersion models are used to estimate airborne contaminant movement, concentration and radiation dose.

Hydrology

Depending on the methods used to seal an impoundment, the potential for seepage will vary. Seepage may enter streams, rivers or potable water supplies through surface runoff or ground water recharge. Accordingly, the hydrologic characteristics of the area are important factors in assessing site suitability. The requirements for water tightness of the reservoir are thus related to this hydrologic evaluation.

The potential for flooding from heavy rainfall and runoff must also be evaluated to permit impounding structure design that will avoid overtopping, erosion and subsequent failure. This is particularly true with cross valley and sidehill types of embankments which may be in the path of large volumes of storm runoff. Adequate storage volume and diversion channels and spillways must therefore be used to prevent pollution of downstream surface waters. The stockpile dam and subgrade disposal structure are the least susceptible to damage from excess surface runoff.

Population Density

Population density and future growth projections should be considered in the selection of a site for disposal of tailings. Tailings dams in the proximity of populated areas may be objectionable for the following reasons:

- Danger of structural failure with resultant release of pollutants
- Fugitive dust and radioactive emissions during operation and after decommissioning
- Aesthetic characteristics
- Possible pollution of potable water sources
- Unauthorized removal of tailings

3.5.3
Current Tailings Disposal Practice

In the past, methods of disposing of uranium tailings have generally followed the methods practiced for waste disposal from other mineral processing plants. A uranium tailings disposal facility, however, has the following unique features:

- Hazards from incorrect dam design or facility management are potentially long-lived because of the long half-life of the radioactive substances involved.
- Required capacity is generally smaller than for a number of other mineral processing operations (2,000 tons per day compared to as much as 100,000 tons per day).

Disposal and Retention Systems

Historically, the following methods of tailings disposal have been used:

- Disposal in bodies of water, including rivers, lakes and oceans. This method is usually inappropriate for uranium tailings due to the nature of the material.
- Disposal in depleted mines.
- Disposal in natural basins.
- Disposal behind embankments constructed of tailings or borrow material.

Rarely can the activities of mining and milling be coordinated well enough for the mined-out areas to serve as the only impoundment site for the tailings. In addition, ground water pollution potential often makes disposal in depleted mines unacceptable unless tailings can be dewatered. France and Canada have implemented such treatment and disposal techniques. In the United States, however, above-ground disposal has been used.

The predominant method for storage of tailings has been disposal and retention behind one of the following embankments:

- CROSS VALLEY – The embankment is constructed in a canyon or valley. The embankment extends from valley wall to valley wall.
- SIDE HILL – The embankment is constructed on the side of a slope. An impounding embankment is constructed on the downhill side, and the uphill ground surface completes the enclosure.
- STOCKPILE – A complete embankment enclosure is built on relatively flat ground.

The cross valley method has been the favored method in the past due to the economics of a single embankment.

Transport and Deposition

Uranium tailings are often transported to the disposal area by pipeline, since this method provides flexibility in siting the tailings impoundment. Pipeline transport and methods of deposition at the embankment are discussed in detail in Aplin and Argall, (1977).

Tailings Embankment Design and Construction

The purpose of tailings dam construction for uranium mills and mines is to safely and permanently contain radioactive materials. Current experience and knowledge in the field of geotechnical engineering as applied to the design and construction of water retention dams must be used. With thorough investigation and planning, economical designs can be produced which ensure safety and prevent contamination. Where it is not feasible to raise a tailings dam in stages because of environmental, safety, or regulatory reasons, construction of a full-height water-retention dam from borrow material or placement of tailings below grade may be required.

Three methods of tailings embankment construction have commonly been used in the mining industry. These include the upstream method, the downstream method and the centerline method. Each method begins with construction of a starter dike. The downstream and centerline methods are shown in Figure 3-12. "Each tailings dam must be developed to meet the specific requirements of the particular project. Downstream methods of dam construction should be used for all but very minor dams located in areas of low seismic activity." (Klohn, 1977).

- THE UPSTREAM METHOD - Historically, this is the most common method because it requires little reworking of the hydraulically deposited tailings. Tailings are discharged from the crest of a starter dike. Coarse material settles out at the dike, with the finer material settling further upstream toward the pond. Each subsequent dike is shifted upstream, with its toe resting on top of the previous dike and its upstream portion over finer material from the previous lift.

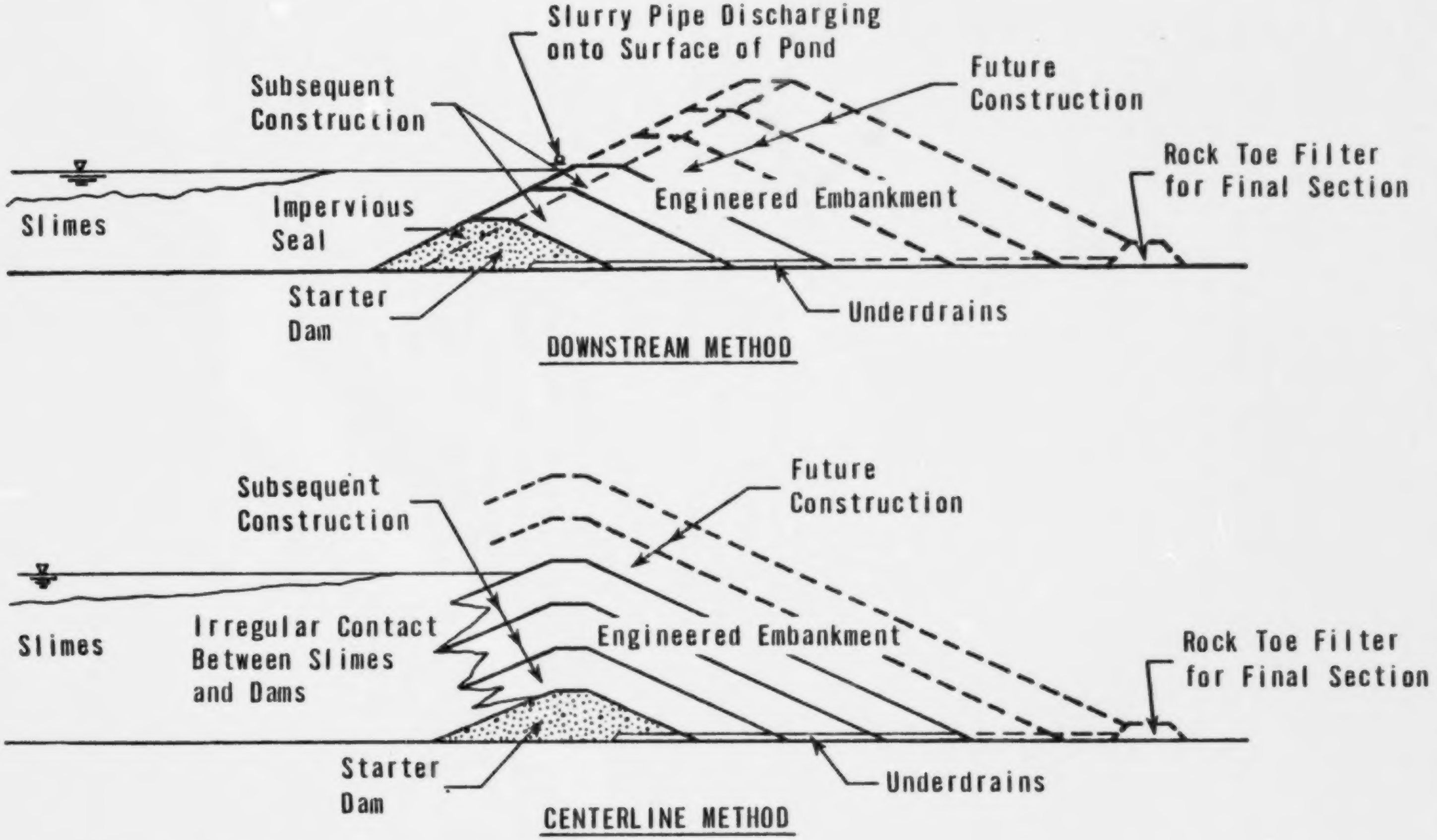
  This type of dam is relatively simple and inexpensive, but it has inherent weaknesses. As the dam height is increased, the critical failure surface shifts from within the coarser material at the downstream face to the lower shear strength finer material and slimes within the dam. Also, the phreatic surface may rise within the dam as the fill height increases. Upstream method impoundments are particularly susceptible to failure by liquefaction under seismic loading or to progressive failure due to erosion or foundation instability. The U.S. Army Corps of Engineers' position on using "upstream lifting (upstream method) for the purpose of achieving an impervious barrier and provide zero discharge for radioactive uranium mill tailings is that it is not acceptable because structural integrity can not be assured" (U.S. Army Corps of Engineers, 1974).

- THE DOWNSTREAM METHOD - Construction begins with an impervious starter dam, which may be built as a homogeneous embankment of impervious borrow material or a zoned embankment with an upstream impervious zone. In the case of the homogeneous embankment, an underdrain is provided to control the phreatic surface (Figure 3–12). The starter dam is compacted in layers to minimize seepage and provide a strong structure. The height of the dam is increased by adding material to the downstream face of the dam. Material added to the embankment can therefore be compacted. The centerline of this type of dam shifts downstream as its height is increased. The impervious zone of the embankment can be carried into the foundation by means of a core trench to create an impervious cutoff. The extent of this core trench depends on the geology of the foundation.

  The major advantage of embankments constructed by the downstream method is the the best modern pratice in the design of earth and rockfill dams can be followed. Therefore, they can be readily built to withstand earthquake forces. The major disadvantage of the downstream method of construction is the large volume of coarse material required for its construction. If sufficient environmentally-acceptable coarse tailings are not available, borrow material may be required. Also, since the downstream slope changes continuously during construction, some measures may be required to prevent wind and rain erosion.

- THE CENTERLINE METHOD - A variation of the downstream method, except that the crest of the dam is raised vertically without a horizontal shift (Figure 3–12). Therefore, only the downstream half of the retention embankment is constructed with the structural integrity and control which is possible for the whole embankment in the downstream method. The advantage of this method is that it reduces the required amounts of borrow materials. The disadvantage is reduced structural stability.

A summary discussion of tailings dam design and additional references are presented in Soderburg and Busch (1977), Short Course, CSU (1978), and NRC Regulatory Guide 3.11.


Slurry Pipe Discharging onto Surface of Pond
Subsequent Construction
Future Construction
Rock Toe Filter for Final Section
Impervious Seal
Slimes
Engineered Embankment
Starter Dam
Underdrains
DOWNSTREAM METHOD
Subsequent Construction
Future Construction
Slimes
Irregular Contact Between Slimes and Dams
Engineered Embankment
Rock Toe Filter for Final Section
Starter Dam
Underdrains
CENTERLINE METHOD

SOURCE: Adapted from Mittal and Morgenstern, 1977

Figure 3-12
Methods of Tailings Dam Construction

Seepage Control for Tailings Embankments

Control of pore water pressure and seepage forces within a water-retaining embankment is essential to overall embankment and foundation stability. Measures must therefore be taken to maintain the phreatic surface at a low level within the embankment. This is basic to modern earth dam design.

Seepage through the tailings embankment may be reduced to a minimum by placing an impermeable seal of clay or a membrane on the upstream face of the dam, or by deposition of tailings slimes on the upstream face of the dam. These methods are only applicable to the downstream method of embankment construction.

In the downstream method, where the whole embankment is controlled fill, the zoning of the embankment is designed to provide drainage within the embankment and keep the phreatic surface low in the downstream zones. Where the embankment is one homogeneous zone, an underdrain is used to draw down the phreatic surface (Figure 3-12). In the centerline method, the same techniques can be applied. However, the full hydrostatic pressure may be present at the centerline of the embankment. If a vertical impervious zone is incorporated immediately downstream of the centerline in the constructed portion of the embankment, a dam equivalent to a conventional dam with an impervious central core can be provided. In the upstream method, no drainage provision can be provided, and high phreatic surfaces may result in many cases. This is one of the factors leading to instability of this type of structure.

In some cases, sand drains or other vertical drains may be required in the foundation beneath the downstream slope of the embankment to control pore pressure due to underseepage in certain foundation geology.

In conjunction with installation of positive seepage control measures within the tailings embankment, various monitoring systems should be installed in the structure. These should include, as a minimum, the following:

- A system of piezometers in the embankment and foundation to define the phreatic surface(s).
- A seepage collection system to monitor volume of flow.
- Wells downstream (i.e. down gradient) of the structure to facilitate environmental sampling.

Further discussion of seepage control measures are presented in U.S. Bureau of Reclamation (1973), and Soderburg and Busch (1977).

Embankment Stabilization

Certain design and construction measures can be taken to stabilize the impoundment and prevent structural failure. These measures, listed below, may also assist in the reclamation program, discussed in more detail in Chapter 4.

- The potential for erosion of the downstream slope of the embankment may be reduced by terracing, placing topsoil and seeding, or placing riprap.

- The potential for saturation and development of excess pore pressures due to continued precipitation or surface runoff inflow may be reduced by several means. Shaping and contouring of the final impoundment surface will prevent areas of ponding. Placement of a clay seal over the final surface will minimize infiltration.

- Placement of topsoil and seeding of the finished surface will enhance the formation of an adequate vegetative cover and will reduce erosion of the impoundment surface. In arid climates it may be necessary to substitute coarse rock to prevent wind and water erosion.

CHAPTER 3

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CHAPTER 4

Siting and Environmental Impact

Once the decision has been made to proceed with a uranium mining and milling project, the operator must decide where to site the facilities and how to mine and process the ore in the most economical and environmentally safe manner possible. His decisions are influenced by many factors, one of which is a continuing concern on the part of government and the public for the effects of mining and milling on the environment and public safety. This concern is manifested in a series of local, state, and federal regulations covering all phases of the project from the pre-mining stage, throughout the active life of the project, to post-reclamation surveillance.

The purpose of this chapter is to highlight the regulations and procedures that the operator incorporates in his project plans, the environmental factors affecting location of mine surface facilities such as the mill and tailings disposal sites, the project activities and their impact on the environment, and the objectives of monitoring, surveillance and reclamation.

4.1
Regulations, Standards and Guidelines

Various federal and state agencies prepare and administer regulations and standards to insure public safety and to protect the environment during development of uranium resources. These agencies also issue guidelines to assist industry in obtaining the required licenses and permits.

4.1.1
Regulatory Authority

The federal agencies primarily involved in uranium mining and milling are the Nuclear Regulatory Commission (NRC) and the Environmental Protection Agency (EPA). The NRC licenses and regulates the nuclear energy industry to protect the public health and safety and the environment. It fulfills its responsibilities through licensing and regulation of nuclear facilities, which include uranium mills. It also develops working relationships with the states regarding regulation of nuclear materials such as processed uranium ore. The purpose of the EPA is to "control and abate pollution in the areas of air, water, solid waste, . . . and radiation" (U.S. Government Manual, 1976). One of its activities is to coordinate and support research and anti-pollution activities by state and local governments. Several other federal agencies may also be involved. For example, in the western states, federal lands are administered primarily by the Bureau of Land Management (BLM) and the U.S. Forest Service (USFS). In addition to the BLM and USFS, the Bureau of Reclamation and the Bureau of Indian Affairs are often involved in approval of rights-of-way or special land use applications or operating plans.

Some of the NRC requirements and guidelines are:

- Requirement for Source Material License (10CFR40.31f)
- Requirement for Supporting Environmental Report (10CFR51)
- "Standard Format and Content of License Applications for Uranium Mills," NRC Regulatory Guide 3.5 (Revision 1, November 1977, distributed for comment)
- "Preparation of Environmental Reports for Uranium Mills," NRC Regulatory Guide 3.8, April 1973 (Being Revised 1978).
- "Design, Construction, and Inspection of Embankment Retention Systems for Uranium Mills," NRC Regulatory Guide 3.11 (Revision 2, December, 1977)
- "Measuring, Evaluating, and Reporting Radioactivity in Releases of Radioactive Materials in Liquid and Airborne Effluents from Uranium Mills," NRC Regulatory Guide 4.14 (distributed for comment June 1977)
- "Quality Assurance for Radiological Monitoring Programs (Normal Operations) Effluent Streams and the Environment," NRC Regulatory Guide 4.15, December 1977
- "Applications of Bioassay for Uranium," NRC Regulatory Guide 8.11, June 1974. A Branch Position for uranium mills is expected in 1978.
- "Instruction Concerning Prenatal Radiation Exposure," NRC Regulatory Guide 8.13, November 1975, Revision 1

The NRC is preparing other guides for inspection and operation of tailings ponds and for slurry pipelines. The NRC also prepares branch position papers to serve as interim guidelines. For example, the Fuel Processing and Fabrication Branch released

"Branch Position: Uranium Mill Tailings Management" in May 1977, which was later incorporated into Regulatory Guide 3.5. The "Branch Position for Preoperational Radiological Environmental Monitoring Programs for Uranium Mills" was released in January 1978. Another branch position paper for operational monitoring will be issued. Copies of NRC regulatory guides and branch position papers may be obtained from the U.S. Nuclear Regulatory Commission, Washington, D.C. 20555, Attention: Director, Division of Document Control.

Some examples of the EPA water, air quality, and radiation protection standards are:

- ENVIRONMENTAL RADIATION PROTECTION STANDARDS FOR NUCLEAR POWER OPERATIONS (40 CFR PART 190, FEDERAL REGISTER, VOLUME 42, NO. 9) were published January 13, 1977. New dose limits for individuals were established to provide protection for populations living in the vicinity of uranium mills and other fuel cycle operations.

  The standards specify that "operations... shall be conducted in such a manner to provide reasonable assurance that... the annual equivalent dose equivalent does not exceed 25 millirems to the whole body,... of any member of the public as the result of exposures to planned discharges of radioactive materials, radon and its daughters excepted, to the general environment from uranium fuel cycle operations and to radiation from these operations" (40CFR 190.10a). As defined in the standard, the term "radiation" (40CFR 190.02e) includes (among others) alpha, beta, and gamma rays, which are most pertinent to uranium milling. The standard defines general environment as the "total terrestrial, atmospheric, and aquatic environments outside sites..." (40CFR 190.02c) of fuel cycle operations, such as the uranium mill site boundaries.

When fully developed these standards will apply to uranium mills and mill tailings. For instance, radon and its daughters were not included in the initial standard. It is expected that these standards will be updated as additional data for the radionuclides become available (Hendricks, 1977).

- EPA LIQUID EFFLUENT GUIDELINES FOR ORE MINING AND DRESSING (40CFR440, Subpart E) when revised will contain effluent discharge limits. Presently the standards are suspended by court order. Originally zero discharge limits were specified.

- RESOURCE CONSERVATION AND RECOVERY ACT (RCRA) OF 1976 defines solid waste to include all radioactive waste not covered by the Atomic Energy Act of 1954, as amended. This includes natural radioactive material and accelerator-produced material. Those solid wastes to be identified are being defined at this time in Section 3001, "Identification and listing of hazardous waste."

  EPA draft hazardous-waste criteria include radium-226 at concentrations equal to or greater than 5 pCi per gram (gm) of dry waste and/or 50 pCi per liter (l) of liquid waste. Disposal of radioactive waste with activities below this level would be regulated by the states using RCRA Section 4004, Land Disposal Site Classification Criteria. Waste exceeding the dry and/or liquid concentrations of 5 pCi/gm and/or 50 pCi/l will be regulated by the EPA or a state through a permit/enforcement regulatory program (RCRA Subtitle C)

  A special study of mining waste is being conducted by the EPA Office of Solid Waste. Following completion of the study the standards for storage, treatment and disposal (Section 3004) will be revised to define acceptable and specific mining waste disposal limits and processes (J.Yeagely, EPA personal communication, 1978).

Since the late 1950's, the states have greatly increased their responsibilities for enforcing and monitoring federal standards and for measuring and mitigating environmental effects of nuclear development within their borders. Congress enacted Section 274 of the Atomic Energy Act of 1954, as amended in 1959 to recognize the interests of the states in atomic energy, to clarify state and federal responsibilities, and to provide for states to enter into formal agreement with the Atomic Energy Commission (now the NRC) for regulatory authority over source, byproduct, and small quantities of special nuclear material (NRC, NUREG-0388, 1977).

States that have been delegated licensing authority for source material under the Atomic Energy Act of 1954, as amended, are called agreement states, and at this date 25 states have developed their own programs and entered into formal agreements with the NRC. Kentucky was the first to become an agreement state, in 1962, and New Mexico was the last, in 1974. Agreement states, in order of effective agreement date, are:

1. Kentucky - 1962
2. California - 1962
3. Mississippi - 1962
4. New York - 1962
5. Texas - 1963*
6. Arkansas - 1963
7. Florida - 1964
8. North Carolina - 1964
9. Kansas - 1965
10. Oregon - 1965
11. Tennessee - 1965
12. New Hampshire - 1966
13. Alabama - 1966
14. Nebraska - 1966
15. Washington - 1966*
16. Arizona - 1967*
17. Louisiana - 1967
18. Colorado - 1968*
19. Idaho - 1968*
20. North Dakota - 1969
21. South Carolina - 1969
22. Georgia - 1969
23. Maryland - 1971
24. Nevada - 1972
25. New Mexico - 1974*

*States with licensing programs for uranium milling activities (Smith, EPA, personal communication, 1978)

States that have not entered into a formal agreement are called non-agreement states. In these states, the NRC maintains its regulatory authority. The non-agreement states include three uranium-producing states: South Dakota, Utah, and Wyoming. In uranium-producing states: South Dakota, Utah, and Wyoming. In non-agreement states, the NRC requires a Source Material License to process or refine uranium ore once it is mined. The NRC license requirements apply to ore that contains 0.05 percent or more by weight of uranium or thorium or any combination of the two prior to processing, such as grinding, roasting, or refining (10CFR 40.4h,k). Agreement states have been delegated (by agreement) the authority for source material; they issue a Radioactive Material License, which is comparable to the NRC Source Material License.

4.1.2
Regulatory Procedures and Permit Requirements

The procedures and requirements for obtaining a permit to mill uranium are similar for agreement and non-agreement states; however, these vary from state to state and with each project. Early during development of project plans the operator contacts the regulatory agencies to coordinate compliance with their requirements, which influence engineering and economic feasibility of the project. The project team should work closely with the agencies to insure completeness of the applications and to develop a schedule that reflects their review procedures. After clarifying what permits are required and what supporting information is needed for each one, a program is finalized. The applicant collects baseline data (including radiological data), provides results of pre-mining investigations, prepares and files applications, and submits detailed project plans.

4.1.3

Proposed Legislation and Requirements

Additional or revised requirements may result from:

- SAFE DRINKING WATER ACT – The states are to develop programs to protect existing and potential sources of drinking water.

- CLEAN AIR ACT AMENDMENTS OF 1977 – The amendments authorize EPA to set guidelines for certain radioactive materials that are presently unregulated (P.L. 95–95, sec. 122(a)). The amendments also have significant implications on uranium projects particularly in meeting national ambient air quality standards (NAAQS) and prevention of significant deterioration (PSD).

  EPA policy has been that NAAQS and PSD increments need not be attained on company property where physical access by the general public is precluded by fence or other physical means (Environment Reporter, February 1978). The EPA is reconsidering the policy which may lead to a revised definition of "ambient air" on company property. Uranium mines and mills would be among sources significantly affected by a policy revision.

The preceding comments are examples of changing regulations prompted by new or revised legislation. The potential technical and economic impact of the legislation during its formulation and after enactment is well documented in comments and reports by government and industry. Investigators and reviewers who need to know more should consult the responsible agency and industry groups.

In a non-agreement state, the applicant's environmental report accompanies the application to the NRC for a Source Materials License. The NRC then prepares a draft environmental statement.

Agreement states have their own licensing procedures, which have to be comparable to the NRC; however, an environmental impact statement may not be required by some states. By example, Table 4-1 shows the permits and time required for the Sweetwater Project uranium mine and mill in Wyoming, a non-agreement state (NRC, NUREG-0403, 1977). The principal agencies involved were the Wyoming Department of Environmental Quality (DEQ), the State Engineer (SE), the Wyoming Industrial Siting Commission (WISC), the U.S. Nuclear Regulatory Commission (NRC), and the Bureau of Land Management (BLM).

When an applicant files for permits or license approvals, the lead agency will request comments from the other agencies involved. Comments will be incorporated into the environmental statement. Project plans will be reviewed to determine if regulatory and bonding requirements are satisfied and if designs have been developed to control and mitigate environmental effects and provide for the safety of the public.

Public hearings may be required once the lead agency review process is complete. After the review and hearings the permit is either granted or denied. The permit may be granted with stipulations which often include performance bonds, specific monitoring and post-reclamation procedures.

The concern about long-term effects of low-level radioactive wastes has resulted in revised regulations for licensing uranium mills and improving tailings disposal systems. The regulations require stringent project decommissioning and post-reclamation

Permit or License	Granting Authority	Date of Application	Date Granted
License to Mine	DEQ-LQD[a]	Dec. 1976 Resubmitted Aug. 24, 1977	Denied In Review
Permit to Mine	DEQ-LQD	Dec. 1976 Resubmitted Aug. 24, 1977	Denied In Review
Air Permit to Construct	DEQ-AQD[b]	May 1977	Aug. 30, 1977
Air Permit to Install Mill Processing Equipment	DEQ-AQD	—	—
Sanitary Sewage Disposal	DEQ-WQD[c]	--	—
NPDES (mine dewatering)	DEQ-WQD	Feb. 1977	Jul. 1977
Mill Waste Water (tailings)	DEQ-WQD	Jul. 28, 1977	In Review
Potable Water Supply	DEQ-WQD	Jul. 28, 1977	—
Waste Treatment Plant ($BaCl_2$ treatment equipment)	DEQ-WQD	Jul. 28, 1977	In Review
Water Wells (18)	SE[d]	Jul. 28, 1977	In Review
Tailing Impoundment	SE	Jul. 28, 1977	In Review
Mill Settling Pond	SE	Jul. 28, 1977	In Review
Mine Dewatering Settling Ponds	SE	Jul. 28, 1977	In Review
Right-of-Way			
Access Road	BLM[e]	Feb. 1977	May 1977
Transmission Line	BLM	—	—
Access Road (Sweetwater County)	County of Sweetwater	Dec. 1975	Jan. 1976 Amended Jun. 1976
Sand & Gravel Pit (mining)	DEQ-LQD[f]	May 1977	Jun. 1977
Site Equipment Staging Approval	DEQ-LQD[g]	—	Jun. 1977
Industrial Siting Permit	WISC[h]	Show cause hearing Oct. 1976	Mar. 1977[i]
Zoning Change	County of Sweetwater	Dec. 1975	Apr. 1976
Final Impoundment	SE	Jul. 28, 1977	In Review
Air Permit to Operate	DEQ-AQD	—	—
Industrial Waste Disposal Site	DEQ-SWMD[j]	Aug. 1977	Withdrawn Refiled Nov. 1977
Source Materials License	NRC[k]	Nov. 1976	In Review

[a] Wyoming Dept. of Environmental Quality-Land Quality Div.
[b] Wyoming Dept. of Environmental Quality-Air Quality Div.
[c] Wyoming Dept. of Environmental Quality-Water Quality Div.
[d] Wyoming State Engineer
[e] U.S. Bureau of Land Management
[f] Obtained via Sweetwater County Engineers Office
[g] Modification to existing DEQ-LQD Permit 302 for open test pit
[h] Wyoming Office of Industrial Siting Administration
[i] Negative Declaration issued March 1977
[j] Wyoming Dept. of Environmental Quality-Solid Waste Management Div.
[k] U.S. Nuclear Regulatory Commission

SOURCE: NRC, DES, NUREG-0403, December 1977

Table 4-1
Status of Approvals and Permits Required for the Sweetwater Project as of November 1977

procedures. A Generic Environmental Impact Statement on uranium milling (GEIS) is to be released by the NRC in the fall of 1978 which may alter future tailings disposal system designs and modify recent license permit stipulations.

4.2
Factors Affecting Facilities Siting

Decisions for siting are made within a framework of engineering, economic and regulatory requirements. The location of the mine is limited to where the ore is; however, some options are available for the mill location. Because the large tonnages of ore have to be hauled to the mill from the mine, the mill should be as close to the mine as possible. The cost of hauling many thousands of tons of ore is one of the major production costs. Another restriction that limits the location of the mill is the need for disposal and storage of the mill liquid and solid wastes remaining after ore processing. With these restrictions in mind, several sites within the project boundaries are usually examined to select the best site for construction and operation of the mine's surface facilities and for a disposal site for mine waste. Similarly, sites are selected for the mill and its large volume of wastes. Economics also dictate that the facilities be located so that they do not interfere with recovery of the ore. In addition to these engineering and economic restraints, the operator is required to design the mine and/or mill to comply with environmental, safety, and radiation protection standards. Environmental factors considered in opening a mine and siting the mill and waste disposal facilities include:

- Topography
- Population
- Geology and geochemistry
- Hydrology, surface and groundwater
- Soils and overburden
- Meteorology
- Biology
- Seismicity
- Cultural features

These factors do not operate independently but are related to each other. For example, hydrology and meteorology are dependent on the local topography. Topography, likewise, is controlled to a large extent by geology. Meteorology at the site is affected by hilly or rugged terrain, since the winds are sometimes channeled along canyons, gullies and water courses.

4.2.1
Topography

The topographic features of a site influence the location of facilities such as buildings, ore storage pads, and waste handling and disposal impoundments. For instance, flat terrain is favored for the location of buildings, storage pads and roads, while sloping terrain is favored for gravity flow from the mill to the settling ponds and tailings impoundments. Stable topography is desirable for siting the permanent facilities. Rapidly changing topography indicates rapid erosion or other mass wasting processes that can cause problems for mine and mill facilities. Of particular importance is the reduction of erosion potential for tailings impoundments.

The topography of a site and surrounding area also influences other environmental conditions, such as meteorology, hydrology, and biology. These influences are discussed in the sections pertaining to the specific conditions.

4.2.2
Population

The proximity to the nearest resident and to important population centers is of concern in deciding where to locate mills or other facilities that discharge radioactive or chemical contaminants to the environment. Population centers include humans, agricultural plants and animals consumed by humans, economically or esthetically valuable wildlife, and indigenous natural populations that are important to the self-maintenance and stability of ecological systems. "Proximity" refers to the nearness of a pollution source to population centers and the degree to which pollutants can contact such populations. The estimated radiation dose is calculated based on populations living within 50 miles of a mill using expected radioactive effluent release estimates, on-site meteorological data, and land use and population data. If no radioactive liquids are to be released, estimates are then prepared for particulate and gaseous effluents. These estimates include mill and tailings site characteristics, the mill equipment performance and exposure to man. Radionuclide doses to individuals are predicted at reference locations such as the nearest permanent residence and at the downwind project-site boundary.

4.2.3
Geology and Geochemistry

Geology is interrelated with the surface and subsurface features of the site, the ore, the project activities and elimination or reduction of environmental impacts. The types of rock materials and their structure not only determine where ore will be found, but influence surface drainage, ground water flows and soil formation. This geologic information is basic to predicting the fate of materials, particularly subsurface effluents. The geochemistry of the sites are determined to show how uranium and other elements and isotopes are distributed and how they may migrate as a result of mining. Open pit mining will alter the subsurface structure, soil profile, land form and hydrology of the local area. To predict the effects of mining a geochemical survey is conducted to provide rock, soil, overburden, plants and water sample data.

The effects of geologic conditions upon the proposed project construction and land use, and conversely the effects of the project upon geologic processes and conditions in the area, are evaluated to satisfy statutory requirements and/or guidelines. For instance, "Recommended Guidelines for Preparing Engineering Geologic Reports for Uranium Mill Siting, Radioactive Tailing Storage and Associated Land Use Changes" was issued by the

Colorado Geological Survey (CGS) in March 1978. The guidelines include regulations of the State of Colorado and the NRC.

4.2.4
Hydrology

The source, quantity, quality and movement of surface and ground waters influence the design of mine facilities and the siting and design of mill facilities and waste disposal systems. Water is required for makeup for mill processes and domestic use. Hydrologic systems can be major pathways for movement and transport of radioactive and chemical waste from mine and mill sites to the environment. In cases where water for mill use is taken from surface or ground water supplies, the impact of water withdrawal on the supply must be evaluated. Depletion of surface water flows and drawdown of local water tables are generally regulated and must not exceed agency requirements, which vary from state to state. The quality of water used for domestic purposes should meet minimum requirements set by state agencies, usually following the U.S. Public Health Service recommended drinking water standards.

The National Pollution Discharge Elimination System (NPDES) permit specifies discharge conditions in those instances where surface waters are to receive liquid discharges from a mine/mill operation. Dilution capacity and water quality must be determined to predict environmental effects in the event of accidental releases and undetected seepage. Dilution capacity increases with flow rate and turbulence of streams. Changes in water quality, such as sediment load and dissolved solids content, which might occur as a result of an accidental mine/mill discharge, may have a significant biological or esthetic impact and possibly provide potential for food chain transport of radionuclides and other contaminants to the human population.

Water systems are major pathways of radionuclide transport to the environment. Radionuclides in seepage from tailings retention systems can migrate downward into aquifers that may appear at the surface as springs or seeps that may affect humans, crops, or livestock. Conversely, radionuclides in surface waters, resulting from aerial deposition or waste discharge, may enter the ground water system by infiltration and affect ground water supplies. Therefore, the relationship and interactions of surface water with ground water must be understood.

The depth to the ground water table is important in the design of mine dewatering systems. Where a mine penetrates the water table, accumulated water must be removed (dewatering). The rate of dewatering depends on the hydraulic characteristics and the depth of penetration of the water table. In the majority of cases, the natural ground water associated with uranium deposits is not suitable for consumption because the radium content exceeds state and federal limits. This water may require treatment to remove uranium, radium or other contaminants before discharge to comply with NPDES permit limitations. Depth to ground water is also important in locating tailings disposal areas, since a large distance between ground water and tailings is desirable. Surface waters and natural drainages at or near prospective mine or mill sites should be examined for erosion and deposition potential. High water runoff from rapid snow melt or thunderstorms can dramatically alter stream channels and cause severe erosion. This should be of particular consideration when siting mill tailings retention systems and ore storage piles.

4.2.5
Soils and Overburden

The soils and overburden at a potential site are sampled and tested to determine the following:

- Chemical and physical properties
- Presence and concentration of radioactive or toxic materials
- Reclamation potential
- Suitability for construction of embankments
- Suitability for construction of surface facilities
- Susceptibility to erosion by wind and water

The analyses of soils and overburden are routinely performed to evaluate project sites. The relationship of the soils and overburden to radioactive or toxic materials movement at the mine and at mill sites is also part of the evaluation.

Soil and sediments usually become a major reservoir for potentially toxic or radioactive materials at mines and mills. Material particles are subject to wind erosion and off-site migration, depending upon particle size, moisture content, vegetation cover, wind speed and other factors. In an open-pit operation overburden properties are determined, since it is often stored, backfilled or used as a substrate in reclamation. Soil properties which affect dispersal of these materials in the environment include porosity, permeability, ion exchange capacity, and erodibility.

If tailings are to eventually be covered with topsoils from the site, the porosity and diffusion coefficients which affect radon diffusion should be known. In general, clay soils provide a more efficient barrier to radon migration than coarse-textured soils. Clay is also somewhat advantageous as a substrate for tailings ponds because of its large capacity to adsorb and retain dissolved radionuclides (Whicker and Johnson, 1978). High adsorption capacity of soil and geological substrate can provide effective protection of subsurface aquifers from radionuclides and undesirable chemicals. The textural properties of surface soils also affect erosion potential and thus determine their suitability in tailings management and reclamation.

The nature of soil and earth materials in contact with surface and subsurface water affects surface water exchange of dissolved minerals and hence, radionuclide migration. In general, the greater the ion adsorption capacity of such materials, the more effectively elements and radionuclides will be retained near a mine or mill site and result in lower concentrations of dissolved radionuclides in water. A disadvantage of fine-grained, highly adsorbent sediments in surface drainages is that they are subject to scouring and long-distance displacement during high water runoff periods. In some cases, adsorbent clay beds are advantageously protected by overlying gravel and boulders in streambeds.

4.2.6
Meteorology

Meteorological conditions influence the dispersion and deposition of airborne effluents, such as stack releases or resuspension of radionuclide-bearing particles eroded from ore or from dry mill tailings. Wind direction determines the overall directional spread of airborne materials. A representative "wind rose" is used to evaluate proposed mine or mill sites. A wind rose is a graphic representation of wind direction and speed frequencies based upon data gathered over some period of time. These data are used to predict prevailing wind direction, mean wind speed azimuth, and frequency of occurrence.

Understanding wind speed regime is necessary to predict radionuclide movement in the vicinity of a mine or mill site and to design an appropriate monitoring program when operations begin. Sources of airborne radioactivity dispersed in the atmosphere largely by wind action are radioactive ^{222}Rn gas, which emanates from uranium ore and from mill tailings; small particles of yellowcake, which are released from dryer stacks; and ore and mill tailings dust generated by human activity or wind resuspension. According to typical Gaussian plume models (Turner, 1970; Smith, 1968), the air concentration at some point downwind of a source is inversely proportional to the mean wind speed which acts upon a plume. Thus, higher mean wind speeds will usually reduce air concentrations and potential radiation doses downwind from such sources.

Another meteorological feature which affects atmospheric dispersion of air-borne materials is the vertical stability of the atmosphere. Vertical stability depends largely upon the temperature structure of the atmosphere. Unstable conditions promote mixing of air-borne contaminants with the atmosphere and stable conditions do not. Vertical stability is often described by the Pasquill stability category (Turner, 1970), which can be predicted reasonably well from wind speed and solar insolation or wind direction variability (wind sigma) data. These data vary according to regional and local topography, the capability of the earth's surface to absorb and reflect solar radiation, and other factors.

Precipitation influences the migration of materials from mine and mill sites. For instance, precipitation increases surface moisture which in turn stabilizes otherwise wind-erodible soils. On the other hand, high runoff may cause undesirable water erosion of ore and tailings. Precipitation also removes particles from the atmosphere through the processes of "washout" and "rainout" (Slade, 1968). This can affect the spatial distribution of radionuclides as well as their route of intake by animals. Precipitation patterns also affect ground water and the subterranean migration of radionuclides. Moisture can also affect the rate of radon emanation through soil cover, particularly in a ground frost situation.

The tendency for ore and tailings dust to become resuspended and entrained in the air stream as well as the process of saltation increases sharply with wind speed. In fact, some studies have shown that soil movement is proportional to the cube of the wind speed (Skidmore, 1976). The net effect of wind speed upon radiation doses around uranium mines and mills depends on the nature of the ore and tailings as well as other factors. Therefore, a general statement cannot be made as to the feasibility of windy sites, except that the problem is complex and should be evaluated for each potential site.

4.2.7
Biology

The ecology of a prospective site and the surrounding area may be affected by mine and mill operations. Of primary concern are the kinds and numbers of organisms and their direct value to man, or their value for maintenance of the character and stability of the environment. Sound management decisions are particularly important if potential sites are on or adjacent to lands with crops, domestic livestock, important game and fish species, or rare or endangered wildlife, because the consequences of operational mishaps or accidents such as tailings dam failures would be worse in such areas than in biologically unproductive areas. Furthermore, food-chain transport of radioactive materials and heavy metals under normal operations may be enhanced in areas that are productive in agriculture, fish or wildlife.

Agriculture, crops and livestock operations adjacent to a mine-mill project have considerable potential to become contaminated with radionuclides or toxic materials like selenium or molybdenum. Cases have existed in the past where contaminated irrigation water and dust from operations have resulted in contaminated crops, and milk and meat products, which constitute part of the human food chain (Whicker and Johnson, 1978). A case of molybdinosis in cattle was reported near an operation where uranium was recovered from lignite ash (P. Smith, EPA personal communication, 1978). While the radiation or toxic exposures to crops, livestock and humans resulting from such contamination may be acceptable and within standards and regulatory guidelines, such exposures can be minimized through careful site selection and appropriate environmental controls.

Fish and game species have economic and ecological values in themselves, and in addition are consumed to varying degrees by humans. Fish and wildlife can use areas not readily controlled by human intervention. For example, waterfowl can use ponds associated with mines and mills, become contaminated, leave the area, and then be consumed by humans. Most terrestrial wildlife can cross ordinary fences and feed adjacent to a tailings retention system and ingest contaminated soil and vegetation. Certain animals can burrow into dams or reclaimed tailings piles, reducing the integrity of the stabilization materials. Fish can concentrate to a remarkable degree certain radionuclides which enter watercourses. For these and other reasons, siting decisions should give due consideration to natural populations and to a reduction in radioactive emissions.

4.2.8
Seismicity

Earthquakes have the potential to disrupt the integrity of tailings dams, mine structures and mill processing facilities. Ground motion and subsequent dynamic response could cause structural failures which could result in the release of radioactive and chemical materials to the environment. Siting and design of mines, mills, and waste retention systems should be consistent with the probability of damaging ground motion. Zones of specific earthquake magnitude have been delineated on a regional basis, and specific sites can be examined locally for faults and other evidence of geologic instability. For seismicity information in the U.S. see Algermissen and Perkins (1976), Coffman and von Hake (1973) and NOAA (1973).

4.2.9
Cultural Features

Historical and archeological sites in the project area may require special consideration in the location of mine and mill facilities. These include natural landmarks and historic sites or areas listed in the National Registry of Natural Landmarks (37 CFR 1496) or the National Register of Historic Places. Contact with the State Liaison Officer - Historic Preservation or Historic Preservation Officer is usually required. Procedures for protection are given in 36 CFR 800.

The archeological significance of the site must also be determined. Steps to recover historical or archeological data are required by the Historic and Archeological Preservation Act of 1974 (PL 93-291), and may affect the development of a project.

4.3
Non-Radiological Impacts

The potential for environmental impacts from uranium mines and mills is greatest during the operational phase of the project when ore is extracted, transported and milled, and wastes are disposed of. The importance of environmental concerns which are generally associated with a uranium project varies with the type of project, method of operation and a multitude of site-related characteristics. Therefore, it is not possible to qualify potential impacts, or in many cases even to predict if they will be significant, until after the project is defined. The project operator has the responsibility to limit operational impacts to acceptable levels, and he must provide evidence of this in environmental reports or other documents which are required to license the project. In all cases, as a condition of licensing, impacts will be limited to comply with regulations set by federal and state agencies to protect the health and safety of the public. In order to limit environmental impacts to acceptable levels, it is necessary to:

- Identify potential impact sources
- Assess the importance of impacts from these sources
- Control impacts, when necessary, by employing specific design or operational measures

The potential non-radiological impacts for a mine and mill include changes in land use, topography, surface and ground water quality, air quality, and biology and soils.

4.3.1
Land Use

Mining and milling operations which remove land from other uses for the duration of the project include:

- Exploration and pre-mining investigations
- Mine development and operation
- Overburden disposal
- Ore stockpiling
- Roads for access and ore haulage
- Utility corridors

Table 4-2 lists the amount of land that has been used for various uranium projects. It is readily apparent from this table that specific land requirements cannot be generalized or predicted from the type or size of an operation. The impacts are more a function of location and size of ore deposits, mining and extraction methods, and duration of activity.

The land use impacts are mitigated by disturbing as little area as possible and by reclaiming the areas disturbed after operations cease, as discussed in section 4.5.

Although most states require reclamation back to productive use, the land use capacity in some areas may be permanently altered.

Project	Mill	Mine		Tailings	Roads	Dewatering	Total
		Present	Projected				
Lucky McMine Gas Hills, Wyoming (open pit-acid leach)	50	2550	500	150	—	—	3150
Bear Creek Project Converse County, Wyoming (open pit-acid leach)	130		2060	153	104	—	~3000
Sherwood Project Spokane Indian Reserv., Washington (open pit-acid leach)	40		155	106	—	—	320
Irigaray Project (in-situ)	5		1000	—	—	—	~1000
Sweetwater Project Red Desert, Wyoming (open pit-acid leach and Heap leach)	87 (400[1])		1600	300	30	3450	~6000
Union Carbide Gas Hills, Wyoming (open pit-acid leach)	225[2]	1500	—	—	—	—	1725
Rio Algom Mine Moab, Utah (underground mine) mill and tailings	2		less than 1 (2-18' holes plus head structures)	25	—	—	27
Atlas Moab, Utah mill and tailings	250 occupied 500 site		no average (supplies from ~30 different mines)	(included in mill)	—	—	250

[1] Heap leach and reclamation

[2] Includes tailings

SOURCE: Compiled by SWEC

Table 4-2

Approximate Land Requirements (in acres) for Various Mine and Mill Activities

For instance, waste disposal areas such as overburden dumps and tailings piles would have restricted grazing if a vegetation cover were not reestablished or if radioactive releases were not controlled. The highwall and pit left after open pit mining would constitute a permanent alteration in land use capability, unless reclamation were undertaken.

4.3.2
Topography

Some topography alterations occur as part of any project operation. Large topographic changes may result from open-pit operations, which generally leave a highwall, a small pit, and a spoils disposal area higher than the local terrain. Also, the construction of mill tailings impoundments and the deposition of tailings into them creates a permanent change in topography. Additional minor changes are caused by roads and other transportation facilities, leveling for construction, drainage diversions, and construction of heap leach pads and in-situ facilities in some proposed operations.

4.3.3
Surface and Ground Water

Surface and ground waters in the vicinity of uranium projects may be affected by a number of project-related activities.

The significance of a particular potential impact on site hydrology is closely related to the type of project, method of operation, and specific site characteristics. Activities which have potential for hydrologic impact include the following:

- Mine dewatering
- Water makeup requirements
- Liquid waste disposal
- Surface runoff

Mine dewatering is required when a surface or underground mine penetrates the local ground water table. Water accumulates in the mine and must be removed so that operations can continue.

Mine dewatering may affect surface and ground water in three ways: 1) by lowering the local ground water table, 2) by changing the water quality in surface and ground water systems, and 3) by increasing the flow in local water systems. Localized lowering of the ground water table (drawdown) usually results from dewatering activities and may interfere with the production of wells drawing from the same aquifer or from a hydraulically connected aquifer. Dewatering may also change the quality of the ground water. As water is continually removed, transport of water from surrounding areas to the area of pumping will occur. If this water is of different quality than the local water, a change in composition will occur. Surface water quality and flow may be changed if mine water is discharged. The magnitude of these changes is dependent on the respective volumes and compositions of the discharge and receiving water. The discharge of mine water would have to comply with NPDES permit limitations.

Water makeup requirements for uranium mills are reported to range from 230 to 400 gallons of water per ton of ore for acid leaching circuits and approximately 60 gallons per ton for an alkaline leaching circuit. Mills using the acid leach process require more water than mills using alkaline leaching because more of the alkaline leach solution may be recycled. Makeup water is obtained from mine dewatering or from wells. In general, the withdrawal of makeup water used in a uranium mill does not adversely impact local water supplies.

Liquid waste disposal is required in the operation of conventional acid and alkaline leach mills. In most cases, the wastes are mixed with spent tailings to form a slurry, which is transported to the tailings disposal area; discharge of wastes to surface waters is not generally practiced. There is generally some recycling of sluice water. The primary waste produced is spent leaching solution, which also contains small amounts of organic process solvents, mostly kerosene. Organics lost to tailings ponds have been reported to be 20 and 160 gpd for 1000-tpd mills and 3000-tpd mills, respectively.

Liquid waste disposal may impact surface and ground water quality. Since liquid wastes are generally impounded with mill tailings, the primary impact of disposal will result from seepage from the tailings pond. Seepage will affect the quality of surface and ground water. The amount of seepage of tailings solution from the pond depends on the depth and size of the pond, the tailings placement and dam construction, the soil encountered, and liner, if any, used. Two reported seepage rates are 45 gpm and 75 gpm for 50-acre and 150-acre impoundments, respectively. Seepage in recent impoundments has been reduced by impervious clay and plastic liners.

Seepage from the tailings impoundment system may have high concentrations of dissolved solids, including heavy metals, and will increase the concentration of these materials in the ground water. Of particular concern are the metals which exhibit higher solubilities at low (acidic) pH and are leached from the ore with uranium in acid leaching. Alkaline leaching is a more selective uranium leaching process and does not dissolve as many metals as acid leaching; therefore, the impact of a unit volume of acid leach tailings solution on dissolved metals concentrations in ground water is greater than for a unit volume of alkaline leach tailings solution. Also, the alkaline leach process produces approximately one-fifth the liquid waste volume of the acid leach process. The quality of surface waters may be altered if ground water reaches the surface.

Surface runoff from disturbed areas may affect the quality of surrounding water and may cause erosion. Due to differences in material characteristics, surface runoff from overburden and waste rock dumps may contain dissolved solids not normally present in surface runoff. Also, prior to reclamation, surface runoff can carry sediments from disturbed areas, including tailings impoundments. This runoff may impact local water quality. Since overburden dumps and backfilled mines (surface mines) contain material that has been excavated and not recompacted to its original density, runoff characteristics from these areas could be different than from surrounding material.

These differences could result in an alteration of local surface and ground water characteristics and quality.

Reducing Hydrological Impacts

The impacts of the operation of uranium mines and mills on surface and ground water systems can be reduced or mitigated in most cases. Although the lowered ground water table resulting from mine dewatering is unavoidable, interference with the production of local wells may be overcome by deepening existing wells, drilling new wells or providing an alternate source of water. Mine water can be used within the project for dust control and mill makeup to reduce the quantity of water discharged, thus reducing the impact on the receiving water body.

Seepage of liquids from the tailings impoundment may be reduced by proper impoundment location, distribution of tailings behind the dam, and installation of an impermeable liner. Because complete elimination of seepage is difficult due to faults that develop in the liner, the ground water needs to be monitored periodically.

Runoff and dam seepage may be collected by a smaller, second dam downstream of the impoundment and returned to the tailing impoundment, thus preventing discharge of tailing solutions to surface waters or drainages. Drainage ditches are employed to divert runoff from the overburden dumps and from the tailing area to minimize the quantity of precipitation entering these areas.

Solution mining impacts are different from those of conventional mining and milling, primarily because leaching solution is injected into the ore body. This process changes the quality of ground water in the uraniferous aquifer. The migration of leaching solution from the field is controlled by changes in the pumping rate (injection and withdrawal) of solution. At the completion of operations at each facility, ground water will be recirculated and treated to restore water quality to an acceptable level. Disposal of liquid wastes is usually by ponding, and seepage from the ponds may alter water quality, as previously discussed.

Heap leaching is a process used to recover uranium from low-grade ore and tailings from abandoned mills. Process water requirements for heap leaching have been estimated to be approximately 200-300 gallons per ton of ore. Since this water is completely recycled, makeup is only required to replace losses such as evaporation. After a water inventory has been achieved, makeup requirements are low. In a properly constructed and operated heap leaching facility, there should be no liquid waste discharge. All process water (that is, leacning solution) is recovered and recycled to the heap leaching area or to the uranium mill as makeup. Seepage of leaching solution to ground water may occur if the pads for the heaps are not impervious or are faulted. Leaching solution would be of low pH with a high concentration of metals, and could affect local ground water quality. Proper construction of the pad minimizes seepage from the heap.

4.3.4
Air Quality

Uranium mining and milling produce two types of air-borne contaminants— gaseous wastes and fugitive dust. Typical air-borne emissions from mills are listed on Table 4.3.

Gaseous wastes result from the combustion of fuels in mining and from vaporization of mill process fluids. Mining equipment is frequently diesel or gasoline powered, and the combustion products are discharged to the atmosphere. The combustion products of concern are unburned hydrocarbons, carbon monoxide, nitrogen oxides, sulfur oxides, and suspended particulates. The quantity of combustion gases released to the atmosphere depends on the number, size and types of mine equipment used and is increased by on-site generation of process steam and electricity. Typical air-borne emissions from heavy equipment are given on Table 4.4.

Although fuels presently used for on-site generation (e.g., propane and light fuel oil) are relatively clean, use of coal in the future may result in increased emissions of sulfur oxides and particulates. Gaseous wastes occur in the milling process in the form of vaporized fluids. These wastes occur in the process area itself (that is, the mill building) and from pond and tailings impoundment surfaces. Since the majority of uranium mills operate with an acid leach circuit, more experience with this process is available than for the other listed processes. Fluid vaporization from alkaline leaching circuits has been estimated to be very low. Ammonia releases from in-situ leaching (ammonium

	Acid Leach	Alkaline Leach	In-Situ Leach	Heap Leach
Process Liquids Vaporization				
Sulfur trioxide	0.2 - 2 lb/day	--	--	NE[3]
Hydrocarbons[1]	100 - 180 lb/day	NE	NE	NE
Chlorine	0.2 - 0.4 lb/day	NE	NE	NE
Ammonia	--	--	55 - 80[2]	--
Yellowcake Dust	0.25 - 5 lb/day	2.5 lb/day	--[3]	--[3]
Fugitive Dust from Dry Tailings Surface	0.4 - 4 lb/acre-hr	0.4-4 lb/acre-hr	--	--[3]

[1] Hydrocarbons are primarily kerosene with small amounts of amines and alcohols

[2] Based on ammonium carbonate as the lixiviant

[3] Values not reported but would be within range for an acid leach mill of similar size

SOURCE: Compiled by SWEC

Table 4-3
Typical Airborne Emissions from Uranium Mills

	Surface Mine		Underground Mine
	Mining lb/day	Stripping lb/day	lb/day
Carbon Monoxide	295	328	42
Hydrocarbons	36	54	7
Nitrogen Oxides	485	539	68
Sulfur Oxides	36	40	5
Suspended Particulates	17	19	3

* Reported values increased to the next whole number

SOURCE: EPA, Assessment of Environmental Aspects of Uranium Mining and Milling, EPA 600/7-76-036, December 1976

Table 4-4
Estimated Emissions from Heavy Equipment at Surface and Underground Mines

carbonate lixiviant) are primarily from lixiviant storage treatment and disposal pond surfaces.

Fugitive dust is produced in both mining and milling. In the mining process, it is produced from vehicular traffic (primarily ore transport), and its impact is generally limited to the vicinity of the mine and haul roads, except under adverse meteorological conditions. Mining also produces dust from overburden and ore handling. In the milling process, yellowcake dust can be released into the atmosphere. The primary impact of fugitive dust is discussed under the effects of mining on vegetation in Section 4.3.5.

Reducing Air Quality Impacts

Mitigation measures to contain gaseous wastes are usually unnecessary because the quantities released into the atmosphere are small and have little impact on ambient air quality. In addition, fuels used for combustion are relatively clean fuels such as propane and light fuel oil, although burning of coal may increase in the future. Vaporization of process fluids generally occurs at a low rate, and the impact on ambient air quality is negligible. Some organics (mostly kerosene) may be contained in the mill tailings and can evaporate; however, since the quantity of organics is low and evaporation is primarily from the surface of the tailings area, the rate of release is low and the impact on ambient air quality is also negligible.

Fugitive dust from vehicular traffic and ore crushing and handling may be minimized by using wet processes and dust-removal equipment.

Yellowcake dust resulting from drying and packaging is generally recovered, and the impact on suspended particulate levels is negligible.

4.3.5
Biology and Soils

Loss and displacement of soils and destruction of vegetation and wildlife habitat are impacts of mining and milling. The removal of vegetation and soils from disturbed areas represents a loss of primary biological productivity on which the local ecosystems depend. Some areas, such as the mine and waste dumps, will be temporarily distrubed and will be reclaimed during mining. Other areas, such as the mill site, tailings disposal area and roads, will be reclaimed after operations cease.

Soils are severely disrupted by most mining activities. Soils as pedogenic units have developed into horizons by natural processes of weathering and biological activity. These soil units are destroyed by removal, transport, and stockpiling. The character of replaced soils will change and, if left stockpiled for long periods of time, will lose the soil organisms responsible for decomposition and nutrient cycling. These soil biological processes are only slowly restored in soils, and may cause reduced plant growth during the early revegetation stage. Fertilizing can partially compensate for the reduced biological soil activity. Vegetation can be affected from dust deposited on leaf surfaces, which may reduce plant vigor. This occurs usually along dirt roads and in the immediate vicinity of mines. The problem is minimal and of short duration.

Wildlife effects are related first to direct loss of animals by construction and mining activities and, secondly, by the loss of food and shelter when plant cover and habitat are destroyed. There is permanent loss of habitat during the life of a project by roads and buildings, and mostly a temporary loss of areas disturbed by mining activity, such as an open-pit operation. Underground mines generally disrupt such small acreage that the effect on wildlife is insignificant. Increased human populations and travel to mining and milling activities impact wildlife such as large mammals and predators that are not tolerant of human disturbances. Other problems are associated with increased human activity and include poaching and shooting of animals in the vicinity of remote projects, increased traffic and road kills, and the use of off-road vehicles.

Mine dewatering may occasionally create temporary aquatic habitat where none previously existed. The effect of new aquatic habitat may increase production and provide habitats for waterfowl and aquatic organisms. One possible detrimental effect of additional water is that the survival of wildlife that may come to depend on it would be threatened by its removal (Wyoming Game & Fish, personal communication).

The impacts on biology and soils can be reduced by reclamation procedures, as discussed in Section 4.5.

4.4
Radiological Impacts

Man is subjected to low-level exposure from natural radiation sources that are a part of the natural ambient environment. These uncontrollable exposures result from radioactive materials in the earth's crust, radionuclides in air and water, and cosmic radiation (EPA, 1977). As a result also of man's activities, he is subjected to additional exposure, which can be controlled. These radiations have been called technologically enhanced natural radiation (TENR) to distinguish them from natural terrestrial and cosmic radiation (EPA, 1977). TENR can result from a number of sources, including weapons testing, medical treatment and diagnosis, uranium mining and milling, fertilizer, supersonic air travel at high altitudes, and burning of fossil fuels.

In uranium mining and milling, only 10–15 percent of the radioactive material in the ore is removed; the remaining 85–90 percent remains in mill tailings. The mining and processing increases the potential for TENR to human populations and ecosystems in the vicinity of uranium projects. Such exposure has the potential, if not controlled, of increasing genetic and somatic effects, such as cancer in occupationally exposed workers and others near a mine or mill. The dose commitment to populations around uranium mines and mills is only a fraction of natural radiation doses and is also much less than medical radiation doses. Quantitative comparisons between radiation dose from natural background radiation, from medical sources and from uranium facilities are provided for a proposed uranium mill in the Chapter 4 appendix.

The annual dose commitments to individuals and populations in the vicinity of a uranium mill are predicted and supplied with the application for a new or continued NRC Source Material License. Included in the supporting data are radiation dose rates from the natural environment in the area and a comparison of annual dose commitments to individuals with respect to existing and future regulations. These data provide a perspective as to the contribution from new or continued operations.

A summary of dose rates from the natural environment is presented on Table 4.5. The existing radiation environment shown is composed mainly of secondary cosmic radiation, cosmogenic radioactivity and terrestrial radioactivity and radiation from offsite sources such as other uranium mining and milling operations. The specific dose rates for the natural radiation sources of exposure are contained in the referenced. NRC Draft Environmental Statement, NUREG-0439, April 1978.

For Wyoming the radiation dose equivalent rate from the natural environment is estimated to be about 185 mrem per year. Additional site-specific natural radiation background data may be required, especially that concerning the radon level for the area to detail the site-specific levels for the project.

The evaluation of radiological impacts is in part based on the predicted annual dose commitments to the whole body, skeleton, lungs, and bronchial epithelium resulting from normal operations.

Source of Exposure	Dose, mrem/yr[a]			
	Whole-Body	Bone	Lung	Bronchial Epithelium
Cosmic radiation				
Direct	77	77	77	-
Cosmogenic radionuclides	1	1	1	-
Terrestrial radiation[b]	88	70	88	-
Internally deposited radionuclides	20	45	20	-
Inhaled radionuclides (chiefly Rn-222)	-	-	1.0[c]	625
Total Dose Rate	186	193	187	625

[a] These doses are typical of the general region; exposure levels fluctuate from area to area, and other data may vary because of this.

[b] Outdoor dose equivalent rates; shielding from building structures is not accounted for.

[c] Inhalation dose due to radon daughters is expressed as dose to the bronchial epithelium.

SOURCE: Adapted from U.S. Nuclear Regulatory Commission, DES NUREG-0439 pg 2-29 April 1978.

Table 4-5
Summary of Typical Radiation Dose Rates from the Natural Environment in the Wyoming area

Table 4-6 summarizes the predictions for dose commitments for an operation in which burial of tailings in clay-lined pits above the water table would be used. The predictions indicate that they are less than the present NRC dose limits for members of the public outside of the restricted areas (10 CFR Part 20; Standards for Protection Against Radiation) and the proposed EPA standard for annual dose commitment (40 CFR 190). In this case the nearest permanent resident was 6.8 miles north of the proposed mill (NRC, NUREG-0439, April 1978).

The population dose commitments were also calculated and found to be "only small fractions" of the dose received from natural background radiation and "also small" when compared to the average medical and dental X-ray exposures currently given to the public for diagnostic purposes (NRC, NUREG-0439, April 1978). The EPA standard does not yet specify the value for doses from ^{222}Rn daughters.

The principal radiological concerns related to uranium mines and mills are:

- Movement of radionuclides in the environment
- Biological effects of radiation
- Control of radioactive wastes and emissions

Receptor Organ	Estimated Annual Dose Commitments, mrem/yr	Radiation Protection Standard, mrem/yr	Fraction of Standard %
PRESENT NRC REGULATION (10 CFR 20)			
Whole body	0.08	500	0.02
Lung	0.28	1500	0.02
Bone	0.26	3000	0.009
Bronchial epithelium	0.0000145 (WL)[a]	0.033 (WL)[a]	0.04
FUTURE EPA STANDARD (40 CFR 190)			
Whole body	0.08	25	0.3
Lung	0.28	25	1.1
Bone	0.26	25	1.0
Bronchial epithelium	0.0000145 (WL)[a]	NA[b]	NA[b]

[a] Radiation standards for exposures to Rn-222 and daughter products are expressed in Working Level (WL). WL means the amount of any combination of short-lived radioactive decay products of Rn-222 in one liter of air that will release 1.3×10^5 mega electron volts of alpha particle energy during their radioactive decay to Pb-210 (radium D).

[b] Not applicable, since 40 CFR 190 does not include doses from Rn-222 daughters.

[c] Nearest private residence 6.8 miles north of proposed mill.

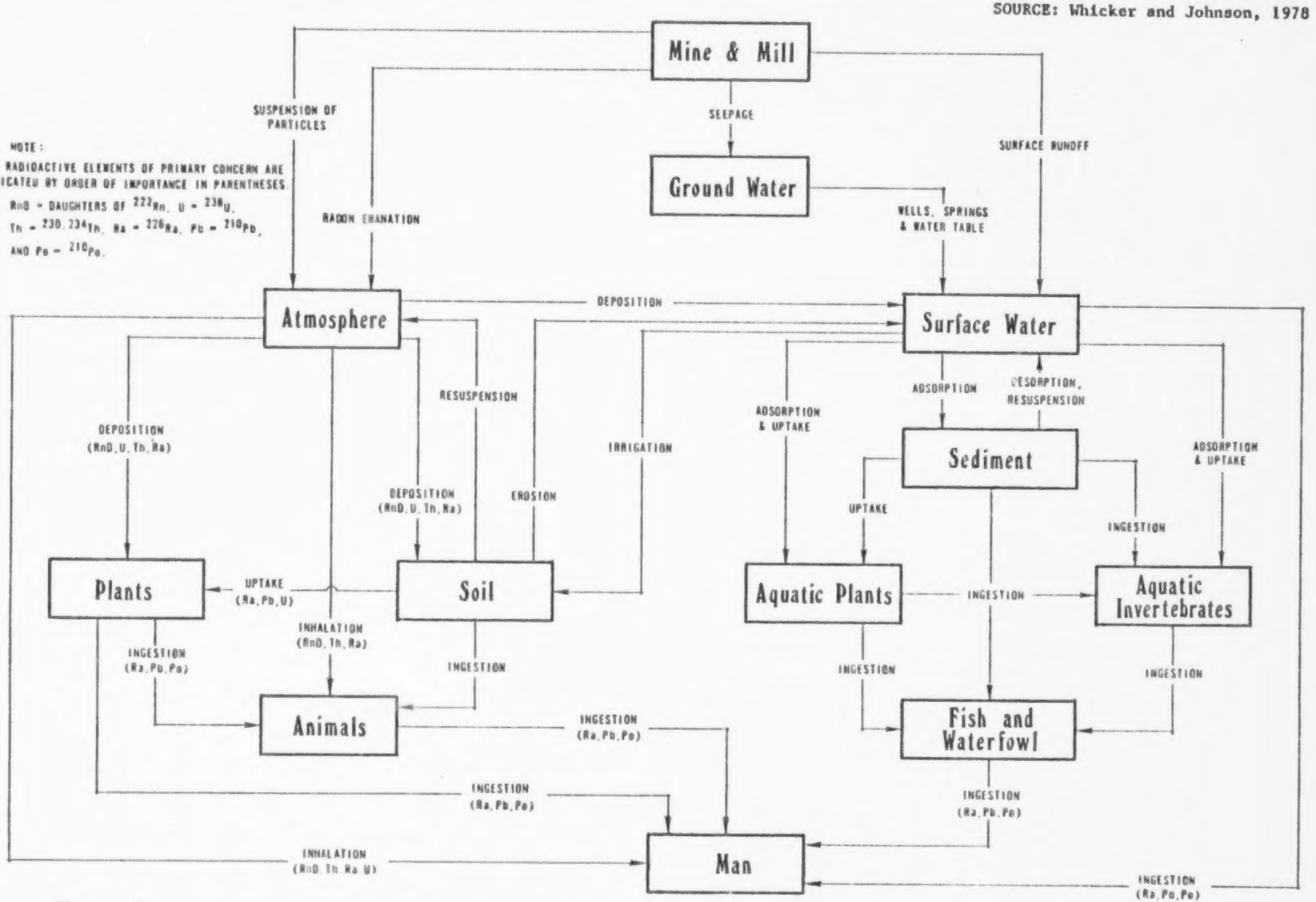
SOURCE: USNRC, DES, NUREG-0439, April 1978.

Table 4-6
Comparison of Annual Dose Commitments to Individuals with Radiation Protection Standards

4.4.1
Movement of Radionuclides in the Environment

Uranium ore contains naturally occurring isotopes of the element and a series of radioactive progeny which are formed by the radioactive decay of parent materials. These radionuclides have the potential for movement in the environment through a number of pathways. A generalized scheme illustrating the principal radionuclide transport pathways around uranium mines and mills is given on Figure 4-1. The boxes represent compartments, or "reservoirs," which contain radioactive materials, and the arrows represent flows or transfers between the compartments. The major processes or mechanisms which cause such transfers are indicated. Not all possible transfer pathways are shown in order to simplify the diagram, but the pathways that are usually of major interest are given. The radionuclides of principal concern are also indicated for some of the pathways. While losses of radionuclides may occur in the system depicted by dispersion in air and water, these losses are not shown. A more detailed description of the radionuclides involved and their transport pathways is given in the Chapter 4 appendix.

The abundance of these radioactive materials depends primarily upon the grade of the ore, which in turn is dependent upon the geological and geochemical history of the ore deposit. The ore body, when exposed to the environment through mining, can serve as a source of radioactivity. Dissemination of radioactive material from an ore body may occur by three mechanisms:


Mine & Mill
SEEPAGE
Ground Water
SURFACE RUNOFF
WELLS, SPRINGS & WATER TABLE
SUSPENSION OF PARTICLES
RADON EMANATION
Atmosphere
DEPOSITION
Surface Water
ADSORPTION
DESORPTION, RESUSPENSION
Sediment
ADSORPTION & UPTAKE
ADSORPTION & UPTAKE
UPTAKE
INGESTION
Aquatic Plants
INGESTION
Aquatic Invertebrates
INGESTION
INGESTION
INGESTION
Fish and Waterfowl
INGESTION (Ra, Pb, Po)
DEPOSITION (RnD, U, Th, Ra)
RESUSPENSION
DEPOSITION (RnD, U, Th, Ra)
EROSION
IRRIGATION
Plants
UPTAKE (Ra, Pb, U)
Soil
INHALATION (RnD, Th, Ra)
INGESTION (Ra, Pb, Po)
INGESTION
Animals
INGESTION (Ra, Pb, Po)
INGESTION (Ra, Pb, Po)
INHALATION (RnD Th Ra U)
Man
INGESTION (Ra, Pb, Po)

SOURCE: Whicker and Johnson, 1978

NOTE:
THE RADIOACTIVE ELEMENTS OF PRIMARY CONCERN ARE INDICATED BY ORDER OF IMPORTANCE IN PARENTHESES.
RnD - DAUGHTERS OF ^{222}Rn, U = ^{238}U,
Th = ^{230,234}Th, Ra = ^{226}Ra, Pb = ^{210}Pb,
AND Po = ^{210}Po.

Figure 4-1
Transport and Movement of Radionuclides to Man

- Emanation of radon gas
- Movement of radionuclide-bearing particles from the surface of the ore body by physical disturbance
- Leaching of the ore body by mobile ground water

Radon gas (^{222}Rn) a daughter product of the uranium decay series, can emanate from the ore body and reach the atmosphere as soon as the ore is exposed in a shaft or open pit. Radon also emanates from the ore in transit and in stockpiles. The rate of radon release is greater with higher grade ore, increased porosity and exposure to the atmosphere. The decay of ^{222}Rn forms a series of radioactive daughter products whose fate depends largely upon the dispersion characteristics of the air in contact with the ore body and the physical nature of the surroundings.

The movement of radioactive particles of ore from the ore body depends upon the physical characteristics of the ore, such as texture and cohesiveness and the physical disturbance to which the ore surface is exposed. Dry ore sometimes generates considerable quantities of radioactive dust as it is mined. Ore stockpiled on the surface, awaiting the milling process, is subject to wind erosion, particularly if it crumbles to form loose particles. Radioactive emissions may result from crushing and grinding of ore, yellowcake drying and disposal of tailings, which contain only a little less radioactivity than the raw ore (except for uranium).

Like exposed ore bodies, mill tailings are subject to radon emanation, erosion by precipitation and wind resuspension, and leaching of radionuclides into the ground water. Tailings are also subject to limited invasion by plants and animals that can transport radionuclides. The chemical processes within the mill may convert some of the radioactive materials in tailings to more soluble, biologically mobile forms than were in the ore.

The actual quantities of radionuclides released to the environment from uranium mines and mills are subject to many variables and therefore differ from site to site. However, some data are available on estimated or measured release rates for currently operating mines and mills. Data for mills are more plentiful than for mines.

The major pathways by which radionuclides are dispersed to the environment are (1) aerial transport of dusts and gases and (2) liquid discharges (see Appendix). Aerial transport of radionuclides may extend well beyond the boundaries of an operating facility. Some approximate figures estimated for airborne release rates from various sources at "model" or typical uranium mills in New Mexico and Wyoming are presented in Table 4-7. It is evident that the release rates vary by source and that ^{222}Rn release rates are far greater than for the other radionuclides. This immediately calls attention to radon and progeny for radiation exposure to populations in the environs of a uranium mill.

There are different contributions by source between acid- and alkaline-leach mills, but the total release quantities are

Source[a]	U	^{226}Ra	^{230}Ra	^{234}Th	^{210}Pb	^{210}Po	^{210}Bi	^{222}Rn
ore crusher & bins	5	5	5	5	5	5	5	37,000
yellow cake	85	1	2	2	-	-	-	-
tailings pond	-	-	-	-	-	-	-	166,000
tailings beach	1	5	9	1	8	8	8	3,240,000
Totals	91	11	16	8	13	13	13	3,443,000

*The values are in mCi/year and represent averages of acid-leach and alkaline leach processes.

[a] Values calculated for operating model mills near the end of their expected life of 20 years.

SOURCE: Adapted from Sears, et al. (1975).

Table 4-7
Estimated Airborne Release Rates of Radionuclides from Model Uranium Mills in New Mexico and Wyoming

similar (Sears et al., 1975). The length of operating time of a mill also affects the effluent releases, with the greatest potential releases occurring near the end of the expected mill life of 20 years when several million tons of tailings have accumulated.

Specific figures for airborne release rates of radionuclides from mines are not readily available. In underground mines, radon is released from the mine ventilation systems in measurable quantities, but few reliable measurements are currently available. In large open-pit mines which have exposed ore bodies that are porous, relatively dry, and spread over a large surface area, the ^{222}Rn emanation rates could approach those of mill tailings systems.

Liquid releases of radionuclides outside the confines of a mill tailings complex through seepage have been estimated below:

Release Rates of Radionuclides to the Ground Water Seepage
(From Acid-Leach and Alkaline-Leach Mill Tailings Ponds)
Values in mCi/year

Process	U	^{226}Ra	^{230}Th	^{210}Pb	^{210}Po	^{210}Bi
Acid-leach	660	51	18,000	51	51	51
Alkaline-leach	690	7	1	6	1	7

Source: Adopted from Sears et al. (1975)

The values shown in the table are based on using tailings material for the tailings dam. In this case the assumption was made that 10 percent of the radionuclides in untreated liquid waste was lost by seepage from the tailings pond. Other cases were examined which assumed a combination of careful siting of the tailings disposal dam, use of earth embankments with clay cores and treatment of the liquid waste. The assumed loss of radionuclides for these various combinations was considerably less, about 0.1 percent of the radionuclides in untreated wastes. These combinations and assumptions are tabulated by Sears et al. (1975).

4.4.2
Accidental Releases

Careful design of uranium processing facilities is required to avoid accidental releases involving radionuclide-bearing materials. Several systems or processes have the potential for accidental releases. These include the release of mill tailings solids or slurry which have the potential for dissemination of the radionuclides and contamination of affected areas. Failure of the air cleaning system used in yellowcake drying and drumming may result in release of radioactive materials into the atmosphere. Transportation mishaps also may result in localized yellowcake spills. Because of the radioactive nature of these releases they must have thorough cleanup and decontamination procedures. The potential for accidental chemical releases should be considered also. For example, reagents used in ore processing may escape because of a rupture in a line or by seepage from a faulty tank.

Operators of uranium mines and mills have the responsibility for cleaning up and decontamination of affected areas. The plans and contingency procedures for treatment of spills caused by accidents need to be coordinated with local and state authorities that may have their own emergency procedures.

In general, accidental releases occur because of improper design or operation or as a result of catastrophic events such as fires, floods, windstorms or earthquakes. Recent tailings spills have been attributed to inadequate design. Examples of these spills are:

- Several leaks in a slurry pipeline prevented development of the tailings beach at the upstream face of the dam. (The slimes in the beach tend to seal the face and contain the liquids.) In this instance, the liquids leaked through the dam.
- A break in a pipe went undetected for several hours during which time the dam eroded causing a breach and loss of tailings downstream.
- During the winter months the height of the embankment was increased with dirt containing snow and moisture. Coincident with the onset of milder temperatures the tailings water was in direct contact with the embankment. A section of the embankment failed and flooded a portion of the mill.

Most accidental releases can be prevented by judicious design and maintenance of safe conditions. However, accidental releases may occur due to natural events beyond the control of the mine or mill operator. The frequency of occurrence and severity of the releases can be predicted and analyzed by using probability statistics and experience from similar operations. Potential effects of the releases can be evaluated and emergency plans and procedures prepared.

4.4.3
Biological Effects of Radiation Dose

Estimates of biological effects can be made by predicting or measuring the radiation dose to populations in areas adjacent to mine or mill sites and relating the dose to biological effects. Prediction of dose first requires the collection of quantitative data on source terms, which describe the quantities and nature of various radionuclides released through time and the circumstances of the releases. Second, environmental transport pathways must be understood, and quantitative parameters must be used to describe dispersion, deposition, adsorption, ingestion, and inhalation. Third, the distribution and retention of various radionuclides in the tissues of organisms must be understood. Finally, the dose in units of rads or rems must be calculated from the tissue concentrations. Dose is usually translated to expected effects on the basis of the studies (NAS/NRC, 1972) dealing with the biological effects of ionizing radiation.

Because of the numerous steps involved in calculating dose and its variability with time and location, it is important to validate theoretically predicted doses by periodic sampling of biota and radiochemical measurement of radionuclides in biological tissues. Such validation is possible for operating mines and mills and can be used in the adjustments and modifications necessary in the development of predictive models. Validated models for a given mine or mill can be used with care to predict the radiological effects of comparable mines or mills in similar ecological settings. In this fashion, operational experience can be used effectively to guide further growth of the industry in an environmentally acceptable manner.

4.4.4
Control of Radioactive Wastes

Release of radioactive materials in uranium mines and mills can be controlled by several means. Dust containing radionuclides from exposed ore, haul roads, and stockpiles can be reduced by watering or applying chemical stabilizers. Dust and yellowcake can be removed from the air in mills by filtering or scrubbing, and gaseous effluents may be released through stacks to promote dispersion. Mill floors can be sloped to a sump where spilled materials can be collected and mill tailings can be discharged to a lined impoundment where all liquids are contained.

When operations cease, tailings can be carefully graded and covered with sufficient overburden and topsoil to reduce radon release. Seeding and fencing of the area completes the initial stabilization. Continued irrigation may be required to establish vegetative growth.

The NRC position is that underground disposal is one of the most environmentally acceptable means of tailings disposal (NRC, Branch Position, May 1977). Underground disposal would eliminate the problem of erosion and, with sufficient cover, the radiological hazards. This method may also be cost effective. Potential problems related to ground water contamination were previously noted. The NRC is suggesting as an option that tailings be dewatered to about 20 percent moisture and disposed into either an open pit or back into an excavation.

4.5
Reclamation, Stabilization and Decommissioning

Most states require reclamation of lands affected by mining, milling and waste disposal. The objective of reclamation is to return these lands to their former use or to a more biologically productive use. Many states require that a reclamation plan be submitted and approved before a permit to mine or a uranium mill license is issued. In Wyoming, for example, the plan and supporting information must satisfy statutes, rules, regulations, standards and guidelines of the state Environmental Quality Act of 1973, as amended, the state Land Quality Division Rules and Regulations of 1975, the Nuclear Regulatory Commission (10 CFR 40) and Regulatory Guide 3.8. In instances where federal lands are involved, U.S. Geological Survey and U.S. Forest Service regulations would apply. The scope of a reclamation plan generally includes decommissioning, stabilization, and reclamation of the mine and mill site and tailings disposal area as well as the procedures necessary for establishing plant growth and restoration of the hydrological features of the site.

Mine reclamation, particularly for open pit mines, is becoming increasingly important in the feasibility, planning and costs of open-pit mining. Contouring, high-wall elimination and back-filling requirements are important considerations. State regulations and interpretations vary greatly. The estimated cost of reclamation is the basis for a surety bond arrangement to insure that reclamation and decommissioning are carried out according to the reclamation plan.

At the present time (1978), the NRC is requiring operators of new projects to update or change their reclamation and decommissioning plans, especially for mill tailings management, as information is developed either from the NRC Generic Environmental Impact Statement on uranium milling or from new research.

4.5.1
Reclamation

Planning for reclamation of affected lands begins with an inventory of the project area soil and overburden, its vegetation and a determination of the suitability of the soil to support plant growth. In addition, the water quality and affinity of wildlife for the vegetative species of the area is also evaluated (Wyoming Department of Environmental Quality, Land Quality Division, Guidelines Nos. 1-6, 1976-78). As an example of reclamation planning, Wyoming requires a pre-mining vegetation inventory that includes a quantitative estimate of plant productivity for evaluating post-mining reclamation. This involves various state agencies depending on the proposed post-mining land use; for instance, state fish and wildlife personnel must be consulted where wildlife habitat is to be restored.

The topsoil is especially critical to reclamation in arid regions of the West. In some areas these soils are not well developed and not present in sufficient amounts to adequately cover the affected areas. Consequently, overburden may be used with stockpiled soil in combination with soil conditioners, fertilizers and chemical stabilizers. The objective of these additions is to promote retention of moisture and air and to provide support and nourishment for plant growth.

The re-establishment of native grasses, shrubs and forbs is essential for wildlife habitat, since the grassland and agricultural crops may not be particularly beneficial to wildlife in some areas. Recontouring to provide varied terrain also enhances diverse wildlife populations.

The Soil Conservation Service has prepared recommended seed mixtures that are best suited to climatic and soil conditions in different areas of the West; hovever, where overburden is used without proper conditioning, the overburden may inhibit infiltration and result in buildup of clay soils. The clay soils are not conducive to plant growth and are subject to surface erosion, which can increase sediment loads into watercourses.

The availability of water is a key factor in reclamation. Water must be available to supplement the natural rainfall to establish the initial plant growth. Although irrigation practices vary, once the vegetation is established it can grow without irrigation within a few seasons.

Reclaimed areas are generally protected from grazing by fencing for at least two growing seasons to allow the plants to become established. Release of surety bonds is dependent on this final step in reclamation.

For an open pit mine and a mill, reclamation may be required for the following:

- Mine pit
- Overburden and topsoil storage areas
- Ore stockpile areas
- Waste or refuse disposal areas
- Mill tailings impoundment
- Embankments or impoundment basin
- Drainage conduit and control structures
- Shop and mill areas
- Processing areas external to the mill
- Access and haul roads
- Other affected lands

Reclamation of mined areas begins and continues during mining. Typically, reclamation of the mine pit begins shortly after the initial stripping operations have been completed and sufficient ore has been removed to permit backfilling of the overburden into the pit. The overburden is graded and shaped to permit topsoil spreading, seedbed preparation, and seeding at the start of the next growing season. Some haul roads may be ripped, graded and prepared as a seedbed for revegetation as the mine pit advances. Also, as some mill tailings impoundment or disposal areas are filled to capacity, the liquids are allowed to evaporate and the tailings are stabilized and revegetated. Other areas are reclaimed using similar procedures at the time the mine and mill operations cease and the facilities are decommissioned.

The overall cost of reclamation may include the cost of the following elements; the combination of these costs depends on the area and project site specifics:

- Topsoil and overburden moving and segregation
- Overburden dump shaping
- Topsoil spreading
- Tailings burial
- Settling pond and mill site filling
- Fertilizing
- Seedbed preparation
- Seeding and seed
- Placement of special stabilization materials
- Decommissioning

An ongoing monitoring and maintenance program may not be required if it can be demonstrated that the reclamation and decommissioning effort has produced a stable area free from wind and water erosion or other distrubance, and that the radioactive and toxic materials are sufficiently contained.

4.5.2
Stabilization

A variety of methods may be used to stabilize the topsoil, overburden or spoil that are stockpiled and used in reclamation of mined areas. The topsoil can support vegetation quickly, although irrigation and plant nutrients may be needed to establish plant growth. Overburden and spoil may be stabilized by covering with topsoil and by revegetation. The piles are graded to a slope of less than 3:1 to reduce surface water runoff erosion.

The mill tailings pose special problems because the waste still contains more than 85 percent of the total radioactivity that was present in the original ore. Therefore, stabilization and reclamation of tailings require special consideration of the long-term potential hazards of radioactivity and possible chemical toxicity. While the tailings retention system is active, surface stabilization is less of a problem because the sands and slimes are covered by liquid except at the tailings beach. After mill operations are complete, the liquid evaporates and the surface becomes dry. Wind related processes, such as saltation, can erode the surface, resulting in radioactive particles being carried away from the impoundment. Covering the surface with overburden and either rip-rap (rock cover) and/or vegetation effectively stabilizes the surface; however, additional measures may be taken to provide protection from radiation, as evidenced by the recent objectives of the NRC and EPA.

The NRC Branch Position of May 1977 requires the operator to minimize erosion, radon emanation and direct gamma radiation from tailings after operations cease. This can be accomplished through tailings removal and below-grade burial, if justified, or through a covering with uncontaminated overburden and soil. Specific performance objectives include:

- Reduction of direct gamma radiation to a level indistinguishable from background in the area
- Reduction of the radon emanation rate from the tailings area to a level no greater than twice that of the surrounding area
- Elimination of the need for an ongoing monitoring and maintenance program following successful reclamation
- Provision of surety arrangements to assure that sufficient funds are available to complete the full reclamation plan

It can be shown by calculation that the first performance objective, reduction of direct gamma radiation, can be achieved by covering the surface of tailings piles with overburden material. Cover in excess of 3 feet can be expected to reduce the gamma radiation levels to nearly background.

Reduction of the radon emanation rate can also be achieved by a cover of overburden. The magnitude of this reduction is a function of overburden depth and porosity to gaseous flow. Since clay is less permeable to gases than coarser materials, it provides a better barrier to the flow of gases and liquids. A clay cap of approximately one-foot-thick covered with 5 1/2 feet of overburden will reduce radon emanation by a factor of roughly 100 (NRC, NUREG-0129, 1977) which should meet the performance objective. Without the clay cap, some 15 feet of overburden may be required to produce the same reduction (Whicker and Johnson, 1978).

Current design objectives for tailings impoundments provide for total containment and the control of the release of material into the environment. Erosion and seepage of solutions are controlled by dams and by lining the tailings ponds with either bentonite clay or an artificial liner. Dikes, berms, and water diversion channels prevent erosion into natural drainages. Wind erosion is controlled by keeping the tailings constantly wet or by chemical stabilization of the edges. Fences control animal access, and pickett type of drift fences can decrease wind velocities at the surface. Specific control measures for tailings impoundments being installed include covering the tailings with overburden and soil to a depth of 6 to 15 feet, bulldozing the edges of the tailings toward the center to reduce the area to be reclaimed; and revegetating.

Revegetation of tailings impoundments can pose special problems if the plants create conditions that accelerate the release of radioactive materials from the tailings. Hendricks (1977) has postulated that plants can take up radionuclides through the roots and release them to the environment or be grazed by animals that may be eaten by man. Radon may also be released through the leaves of plants. The alternative to revegetation is to riprap the surface with rock or otherwise stabilize the tailings surface. Plants stabilize a soils surface, and since the period of time in which radioactive releases are a concern is in thousands of years, stabilizing the tailings surface with mechanical means is only a short-term solution. Natural processes of soil formation and plant succession will revegetate all but the most resistant rock surface in a few hundred years.

Use of tailings impoundment areas after reclamation may be restricted. At the Bear Creek project, Lucky Mc Uranium Mill, and the Sweetwater Project, the NRC has placed the following restrictions on the tailings disposal system (NRC, NUREG - 0129, 0295, 0403, 1977):

"1 The holder of possessory interest will not permit the exposure and release of tailings materials to the surrounding area.

2 The holder of possessory interest will prohibit erection of any structures for occupancy by man or animals.

3 Subdivision of the covered surface will be prohibited.

4 No private roads, rails, or rights-of-way may be established across the covered surface."

More recently, the NRC has proposed burial of tailings in open pits or excavations to solve the long-term problem of erosion and radioactive releases. This is in line with the NRC position that future tailings disposal systems be designed to eliminate the need for long-term monitoring and care. At present there is no experience with this system of tailings disposal and there has been no evaulation of potential problems such as transport of tailings and ground water contamination. Nevertheless, the NRC and uranium industry are currently evaluating this method for technical and economic feasibility.

Continued research is leading to a better understanding of tailings management. Literature dealing with tailings rehabilitation issues includes Schiager, 1974; Goldsmith, 1976; Bernhardt, Johns and Kaufmann, 1975; Kaufman, Eadie and Russell, 1976; Scarano, 1977; Ford, Bacon and Davis Utah Inc., 1977.

4.5.3
Decommissioning

The NRC requires a decommissioning plan, including estimated costs and surety arrangements at the beginning of a project. A more detailed plan is required near the end of the useful life of the project (NRC, NUREG-0403, December 1977). The plan for a mill may include:

- Decontamination of the processing facilities
- Disposal of fuels and chemicals
- Dismantling and removal of buildings and structures (power lines)
- Burial of foundations
- Covering of buried materials, grading, covering with topsoil and revegetating

In some cases selected buildings, structures, roads, wells and flood control ponds may be left for future use by the land owner. The mill site area will be contoured, layered with topsoil and also revegetated. Radiation surveys may be conducted to demonstrate that levels of radioactivity are within prescribed limits and that the decontamination procedures were successful.

4.6
Monitoring and Surveillance Programs

Federal and state agencies require that monitoring programs be designed and approved before any significant development activities begin and that these programs continue during operations. After operations cease and reclamation procedures are complete, surveillance of the project site may be required to measure the success of reclamation and to demonstrate that the requirements of the performance bond have been met. As noted in Section 3.5, NRC performance objectives include elimination of ongoing monitoring and maintenance following successful reclamation.

Preoperational and operational monitoring programs are conducted to predict and evaluate the impact of mine and mill operations. The major elements of the monitoring programs include:

- Establishing sampling procedures, frequencies, material to be collected, and types of analyses
- Maintaining accurate records in an accessible form, including the traceability of samples
- Analyzing and interpreting data
- Periodically reviewing the results and updating programs

NRC prescribes monitoring requirements in non-agreement states, and agreement states pattern their programs after the following:

- NRC Regulatory Guide 3.8, Preparation of Environmental Reports For Uranium Mills (1973)
- NRC Regulatory Guide 4.14, Measuring, Evaluating, and Reporting Radioactivity in Releases of Radioactive Materials in Liquid and Airborne Effluents From Uranium Mills. Distributed for comment, June 1977.
- "Branch Position For Preoperational Radiological Environmental Monitoring Programs For Uranium Mills" (1978)
- "Proposed Branch Position For Operational Radiological Environmental Monitoring Programs For Uranium Mills" (1978)

The sampling parameters needed to satisfy the non-radiological aspects of a uranium project are usually similar to any other mining project. Sampling for radionuclides is conducted either on a more frequent or continuous basis.

4.6.1

Preoperational Monitoring

The objective of preoperational monitoring is to measure the characteristics of the site prior to mining or mill construction activities. The impact from these activities may be predicted using modeling techniques and site measurements. These data also serve as a reference for monitoring the impacts that result from construction and operation.

Section 6.0, Effluent and Environmental Measurements and Monitoring Programs, of NRC Regulatory Guide 3.8, sets forth objectives and information needs for the applicants preoperational program for each of the following:

- SURFACE WATERS
- GROUND WATER
  Physical and chemical parameters
  Models
- AIR
  Meteorology
  Models
- LAND
  Geology and soils
  Land use and demographic surveys
  Ecological parameters
- RADIOLOGICAL SURVEYS

The radiological surveys are not classified further in the Guide, but they may include:

- External gamma radiation
- Radionuclides in soils
- Radioactivity analyses of water
- Biological radioactivity
- Airborne radioactive dust
- Radon in air

Instrumentation, scheduling, techniques and procedures are emphasized in Section 6.0 of Regulatory Guide 3.8.

The NRC Branch Position for preoperational radiological environmental monitoring programs specifies the need for data on background radionuclide concentrations and radiation dose rates at the mill site and vicinity prior to operations. The data is required for:

- Assessing radiological impacts of the future milling operations
- Determining compliance with applicable environmental standards
- Base line reference data at time of site decommissioning

The data from the program may include many of the components listed in the example program illustrated in the NRC Branch Position. In general, the sampling media, the frequency of sampling, and types of analyses performed will be continued during operational monitoring. Typically, preoperational monitoring begins one year before milling operations start. Similarly, this type of monitoring is conducted prior to mining.

4.6.2
Operational Monitoring

The elements of the operational program also set forth in Section 6.0 of NRC Regulatory Guide 3.8 are:

- Mill-effluent monitoring
- Environmental Radiological Monitoring
- Chemical effluent monitoring
- Meteorological monitoring
- Ecological monitoring.

In the case where the proposed project includes a uranium mine, a mine and mill effluent monitoring program is required. An example of an operational monitoring program is shown in Table 4-8. This example is a proposed program for the Sweetwater Uranium Project, and therefore it may be modified somewhat by the time it is finally approved by NRC. The environmental elements and materials sampled include all of the five elements cited in the Regulatory Guide 3.8.

After the applicant submitted the program, the NRC issued a proposed Branch Position For Operational Radiological Environmental Monitoring Programs For Uranium Mills (NRC, Proposed Branch Position, 1978). The NRC has formally defined the measurement data needs for radiation dose rates and radionuclide concentrations in the mill site environs.

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Environmental Element & Material Sampled	Sampling Program			Sample Analysis Frequency	Isotope, Radiation, or Chemical Identified
	Location	Method	Frequency		
Ambient Air					
Suspended particles	6 Locations, at least 3 downwind of the site	High volume air sampler	Continuous	Quarterly (composite)	Total suspended particles, U-nat, Ra-226, Th-230, and Pb-210
Clean air	6 Locations, at least 3 downwind of the site	GRAB 0.5-2 L/min for 1 week	Monthly (1 week continuous per month)	Monthly	Rn-222 Ra-222
Effluent Air	Yellowcake drier and packaging stacks	Representative GRAB	Semi-annually Quarterly	Semi-annually Quarterly	Th-230, Ra-226 U-nat
	All mill stacks	Representative GRAB	Semi-annually	Semi-annually	U-nat, Total suspended particulates
	Roof vents, s-x bldg.		Annually	Annually	Total hydrocarbons, NH_3
Ground Water					
Monitor wells	4-6 Locations near tailings impoundment	GRAB	First year: monthly, quarterly	Monthly Quarterly	U-nat, Ra-226 Th-230, Pb-210, chemicals[a]
			Following yrs: quarterly, annually	Quarterly Annually	U-nat, Ra-226 Th-230, Pb-210, chemicals[a]
Monitor wells	4-6 Locations near mining & mill sites, including potable water supply	GRAB	First year: quarterly, annually	Quarterly Annually	U-nat, Ra-226 Th-230, Pb-210, chemicals[a]
			Following yrs: semi-annually, annually	Semi-annually Annually	U-nat, Ra-226 Pb-210, Th-230, chemicals[a]
Tailings Liquid	Tailings pond	GRAB	Annually	Annually	Pb-210, U-nat, Ra-226 Th-230, pH
Ambient Radiation					
Direct external exposure	6 Locations (same as ambient air stations)	Thermo-luminescent dosimeters	Continuously	Quarterly	Gamma, Beta
Mine Dewatering Discharge	Settling ponds outlet	GRAB	Per NPDES Permit	Per NPDES Permit	Per NPDES Permit (see Appendix D)
Topsoil	6 Locations	GRAB (0-2") (2"-5")	Annually	Annually	U-nat, Ra-226, Th-230 Pb-210, Gross
Biota					
Vegetation	6 Locations (Same as soil)	GRAB	Annually	Annually	U-nat, Ra-226, Th-230 Pb-210

[a] Chemical parameters to be analyzed for will be determined from an analysis of samples taken from the tailings pond once operations of the mill have begun.

SOURCE: NRC, DES, NUREG-0403, December 1977.

Table 4-8

Operational Monitoring Program

"These measurement data are needed:

- To demonstrate or confirm compliance with applicable environmental radiation standards and regulations, e.g., 10 CFR 20, "Standards for Protection Against Radiation" and 40 CFR 190, "Environmental Radiation Protection Standards for Nuclear Power Operations (EPA Uranium Fuel Cycle Standards)." Section 20.201 of 10 CFR 20 entitled "Surveys" requires that a licensee conduct such surveys of concentrations of radioactive materials as may be necessary to demonstrate compliance with the regulations.
- For use by the NRC staff in evaluating the environmental impact of the radioactive effluents from the milling operations including estimates of the potential radiation doses to the public.
- For evaluation by the NRC staff of the adequacy and performance of effluent control systems and procedures, including tailings retention systems."

The NRC stresses effluent measurements off-site rather than at the point of release because of the difficulty of taking direct measurements for sources such as tailings piles and ore storage pads. The NRC lists several essential program elements: air, water soil, and vegetation or forage sampling, and direct radiation measurements.

- AIR SAMPLING - Ambient air quality is sampled because of the potential radiological hazard from airborne ore, yellowcake and dusts as well as radon gas generated from radium contained in tailings.
- WATER SAMPLING - Water is sampled because several of the radionuclides in the tailings may be leached and leave the site by ground water or surface water movement.

  Ground water must be collected from sampling wells located down gradient around the designated tailings disposal area. Hydrological data are used to place these wells in the predominant flow direction away from the site. A control well is located upgradient above the tailings site disposal area. Drinking water or livestock well water is also sampled.

Surface water must be collected from large water impoundments near the mill site that may be subject to surface drainage or influenced by seepage from the tailings site. Samples of surface water are also collected upstream and downstream of the mill site.

- SOIL SAMPLING - Surface soil samples are taken as a measure of area radioactivity contamination due to site operations. Contamination could result from airborne dispersion or transport due to liquid effluents or runoff. These samples are taken at the same locations for air particulate samples.

- VEGETATION OR FORAGE SAMPLING - Samples of plants that serve as forage for local wildlife or livestock are important to collect for two reasons. First, since plants generally have large surface areas, they are collectors of radioactive contamination resulting from the operation. Secondly, plants are part of terrestrial food pathways to wildlife, livestock and eventually to humans.

  The sampling is considered necessary if dose calculations show that ingestion of meat from these grazing animals constitute a potentially important exposure pathway.

- DIRECT RADIATION MEASUREMENTS - Gamma rays from radionuclides are measured at the same locations as air particulate samples to obtain gamma dose rates.

The specific number, frequency and type of analyses required for each of the program elements are outlined in NRC's proposed Branch Position. Although the NRC position is not final, each program element is reviewed on a site-specific basis, and final approval of these is documented in the Final Environmental Impact Statement for the proposed project.

4.6.3
Post-Reclamation Surveillance

Surveillance is necessary to determine that reclamation has been successful. Revegetation is necessary to restore productivity and to meet surety requirements. Stabilized areas should be periodically checked, particularly if there is a potential radiological or chemical hazard.

Radiological and chemical surveillance should continue until it is determined that no significant release of material is probable. The tailings impoundment design, the reclamation procedures, and the type of stabilization of any other material produced or stored onsite will determine the extent and duration of the surveillance program.

For instance, surveillance and monitoring activities may be more frequent at first and then diminish as the land and reclamation adjust to normal cycles. If no change in the project site is detected after a period of time, usually 5 to 25 years, then inspection of the area will only be necessary on a long-term basis.

The long-term institutional controls that govern the use of the project site or use of materials from the site have yet to be established. In the past, tailings were used as fill in the construction of residences. Radon emanating from the tailings was trapped in the dwellings resulting in a radiological health hazard to the occupants due to inhalation of radon and its daughters. An expensive remedial program was required to remove the tailings from under the homes. The questions of who has title to project lands after mining and milling has ceased and of how to provide continued protection of the public are unresolved and remain the subject of regulatory agency review and public comment.

Two reports which address the problems of long term controls are the EPA Background Report, Considerations of Environmental Protection Criteria for Radioactive Waste, February 1978, and the report by the Western Interstate Nuclear Board Committee on Mining and Milling of Nuclear Fuels, Policy Recommendations on Financing Stabilization, Perpetual Surveillance and Maintenance of Uranium Mill Tailings, April 1977.

CHAPTER 4

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CHAPTER 4

Appendix

This appendix contains discussions of the following topics:

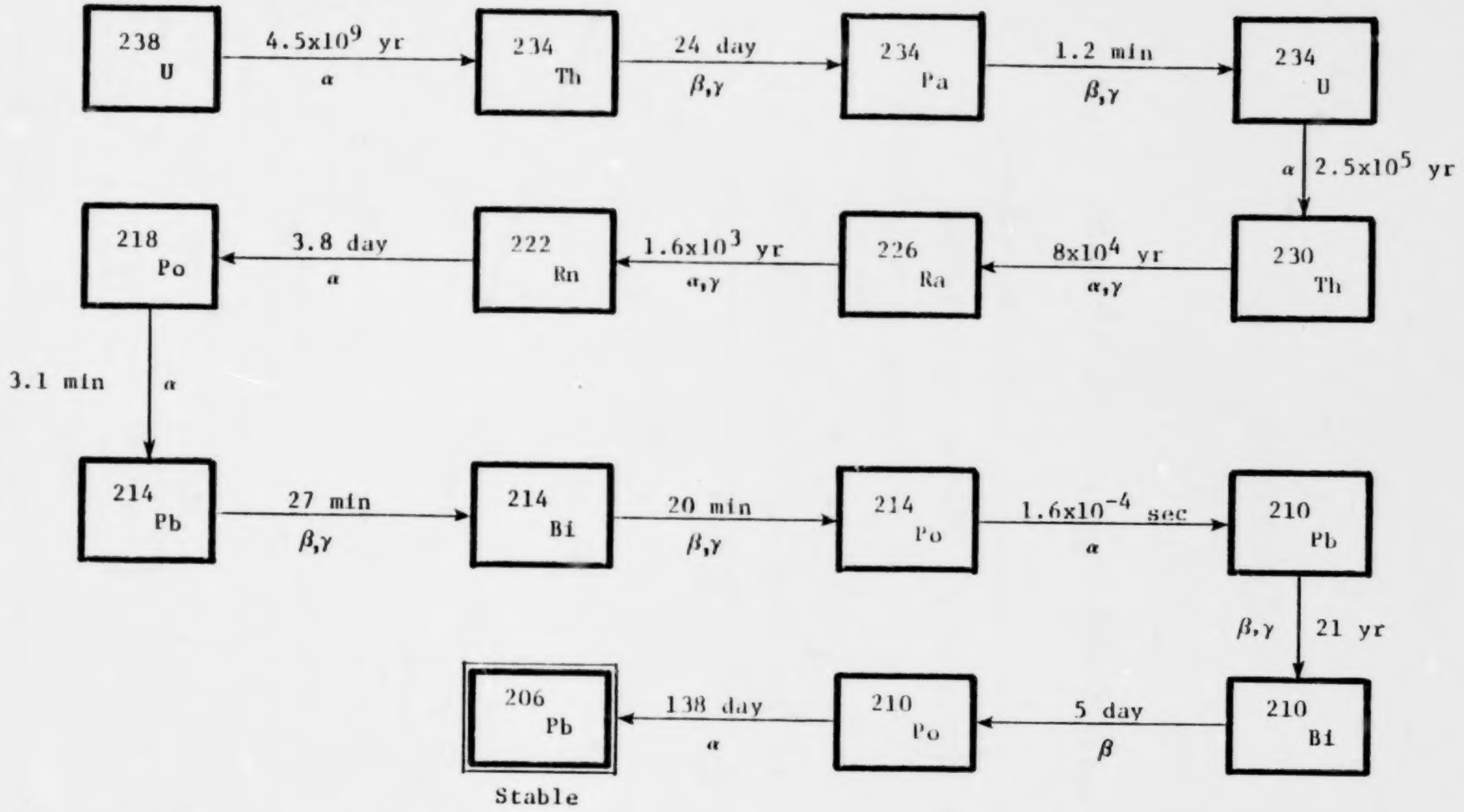
- radionuclides of the uranium decay series
- radionuclide transport and exposure pathways
- prediction of radiation dose
- radiation dose rates and their significance

Also included are tables that summarize estimated dose rates from background sources of radioactivity and from uranium mills.

A-1
Radionuclides of the Uranium Decay Series

The radionuclides extracted from uranium ore are fissile ^{235}U and fertile ^{238}U. Some 99.28 percent of natural uranium is ^{238}U, while only 0.72 percent is ^{235}U. The potential radiation contamination from uranium mining and milling arises not so much from the uranium itself, but from the radionuclides generated by its decay. Natural uranium exists in the earth's crust because of the long half-lives of the principal uranium isotopes. The physical half-life of ^{238}U is 4.5 billion years, and that of ^{235}U is 0.7 billion years. The radioactive decay of ^{235}U and ^{238}U generates shorter-lived daughter products at an essentially constant rate as measured in terms of human experience. Although both ^{235}U and ^{238}U generate a series of radioactive products, the ^{238}U chain is discussed due to the abundance of ^{238}U.

The ^{238}U series includes 13 principal radionuclides in addition to the primordial parent (see Figure A-1). The series terminates with the formation of stable ^{206}Pb. Secular equilibrium of ^{238}U


238 U
4.5x10^9 yr
α
234 Th
24 day
β,γ
234 Pa
1.2 min
β,γ
234 U
α
2.5x10^5 yr
230 Th
8x10^4 yr
α,γ
226 Ra
1.6x10^3 yr
α,γ
222 Rn
3.8 day
α
218 Po
3.1 min
α
214 Pb
27 min
β,γ
214 Bi
20 min
β,γ
214 Po
1.6x10^-4 sec
α
210 Pb
β,γ
21 yr
210 Bi
5 day
β
210 Po
138 day
α
206 Pb
Stable

SOURCE: Whicker and Johnson, 1978

Note: Half lives and major types of radiation are shown. Alternate, less frequent branching decays are not shown.

Figure A-1
The Primary Decay Series of Uranium - 238

and daughters is usually assumed for geological deposits, which means that daughter and parent activities, expressed as curies, or disintegrations per unit time, are equal. Chemical, physical and biological processes can act upon a sample of ore to cause chemical separation of some members of the uranium decay series, disrupting secular equilibrium.

During milling, about 85–95 percent of the uranium is recovered from the ore as uranium oxide (yellowcake). The mill tailings, therefore, are depleted in the uranium isotopes. They are also soon depleted in ^{234}Th and ^{234}Pa as well, because these nuclides are being produced at a much reduced rate and the amounts present decay in a matter of months to innocuous levels, owing to their short half-lives. However, long-lived ^{230}Th maintains the chain of radionuclides from ^{226}Ra through ^{210}Po.

In tailings, however, several complications can arise. For instance, ^{226}Ra and ^{230}Th may separate to some extent, disrupting secular equilibrium between the two radionuclides. In addition, gaseous ^{222}Rn can escape from the tailings, quite rapidly in some cases, to form a partial discontinuity in the secular equilibrium of the decay chain. The degree of this discontinuity is dependent upon the rate at which radon can diffuse away from its source, ^{226}Ra. If diffusion is very poor, essentially all the ^{222}Rn will decay in place, and secular equilibrium is likely to be maintained through ^{206}Pb. If a large fraction of the ^{222}Rn atoms diffuse from the tailings to the atmosphere, the daughter nuclides of radon will show reduced activity levels in the tailings with respect to ^{226}Ra.

Calculation shows that a curie of ^{226}Ra will produce a curie of ^{222}Rn every 5.5 days, or 0.18 Ci/day. A most important objective of tailings management is to reduce the escape of radon to the atmosphere because it usually produces a greater radiation dose to humans, plants, and animals around a mill than any other process.

The most commonly monitored radionuclides occurring around mill tailings include ^{230}Th, ^{226}Ra, ^{222}Rn, and ^{210}Pb. Thorium-230 is a long-lived alpha emitter that lodges primarily in bone if assimilated. Fortunately, because of its low solubility ^{230}Th is not readily taken up by plants or assimilated by animals. However, it can enter the body through inhalation and become a more significant hazard than other radionuclides in mill tailings dust (ICRP, 1960).

Radium-226 generally poses a greater ingestion hazard than ^{230}Th because it forms more soluble compounds and behaves chemically in a manner similar to calcium, an essential nutrient element. It is therefore assimilated by both plants and animals. Radium-226, an alpha emitter, lodges tightly in the bone matrix, and in sufficient levels, it has produced bone cancer in humans (Evans, 1967; Finkel, Miller and Hasterlik, 1969). Overall, ^{226}Ra is of more concern than the other radionuclides in mill tailings from the standpoint of food-chain transport processes.

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Radon-222 can pose perhaps the greatest biological risk around uranium mines and mills because it can be released into the atmosphere in large quantities from exposed ore or tailings, and its decay produces a series of seven radionuclides which can be inhaled or enter food chains. These daughter products of ^{222}Rn generally produce a much greater health risk than does radon itself. The reason for this is that radon is a noble gas and is not easily absorbed or adsorbed by biological surfaces.

Lead-210 is long-lived and has some potential to accumulate in or on biological tissues. It is also a bone seeker with an intermediate tendency to be assimilated. Levels of several other radionuclides, such as ^{218}Po, ^{214}Bi and ^{210}Po, can sometimes be inferred from measurements of ^{222}Rn and ^{210}Pb (Evans, 1967).

A substantial body of information exists about the levels of radionuclides in ore and mill tailings and on the quantities which can be released to the environment (Sears, et al., 1975). There is much less data, however, on the behavior of these radionuclides once they enter ecological systems.

A-2
Radionuclide Transport and Exposure Pathways

Ionizing radiation emitted from the radionuclides associated with uranium mining and milling impact biological populations in two ways. One is by internal irradiation from radionuclides deposited within tissues, and the other is by external irradiation from radionuclides that are near but external to the exposed biological tissues. The radiation dose received is therefore highly dependent upon the amounts of radioactive material that enter the organism as well as the amounts that reside in the immediate environment. In order to predict these amounts, the environmental transport pathways must be understood and quantified.

Two routes of radionuclide transport involve aquatic and terrestrial systems. Transport between these systems is possible through erosion, irrigation, and aerial deposition. As indicated, mine-mill effluents reach the terrestrial environment mainly through erosion of radionuclide-bearing particles of ore, tailings or yellowcake, and through emanation of gaseous ^{222}Rn from ore and tailings. Aquatic systems receive radionuclides by surface runoff, seepage into the ground water, aerial deposition, and erosion of contaminated soil. Ground water may appear on the surface through wells, springs, or a rising water table associated with topographic depressions or increased hydrostatic pressure.

Radionuclides in the atmosphere are subject to dispersion, directional transport, deposition, and inhalation. Dispersion and transport are determined by meteorological factors such as wind speed, direction, and turbulence, and by precipitation.

Deposition by gravitation forces, impaction, and rainout or washout (Slade, 1968) results in the contamination of soil, vegetation and surface water. The smaller (<10 microns) aerosol particles may be inhaled by animals and man. Material which has been deposited on the soil can become resuspended by wind and other kinds of physical disturbance. This material thus becomes subject to further dispersal and deposition at a distant location.

Radioactive materials in surface waters are subject to complex processes involving dispersion, physical transport and absorption and/or adsorption by sedimentary material, aquatic plants and animals. Surface waters may be applied to the land for irrigation purposes or consumed by humans and wildlife. Dispersion and transport is determined by the nature of the hydrological system and the sediments and aquatic biota. Absorption and desorption processes are complex, depending upon physical, chemical and biological factors.

Populations contaminated with radioactivity are of concern for three major reasons. First, radionuclides incorporated into living tissues are subject to food chain transport and may reach man. Second, radioactive material may be spread from a site of contamination by movements of plants and animals. Third, the radioactivity may have a detrimental effect upon the organism itself. Food chain transport of radionuclides in terrestrial ecosystems involves ingestion of contaminated plant or animal tissues and assimilation and incorporation of the material. Terrestrial food chain transport to man largely involves consumption of crops and domestic animal products, although wildlife species are also consumed by a fraction of the population. Aquatic food-chain-derived material can reach man through consumption of fish and waterfowl. As mentioned previously, food chain transport involves chemical and physiological processes and there is discrimination at biological membranes. Of the elements involved in the uranium series, radium is most readily assimilated by most organisms. Lead and polonium are intermediate in their level of absorption by organisms.

External exposures to organisms from radionuclides in the environment arise principally from gamma rays and secondarily from beta particles. In most ecosystems the soil is usually the predominant reservoir of radioactivity. Thus, the decay of gamma-emitting radionuclides in soil normally accounts for a large fraction of the external exposure received by plants and animals.

A-3
Prediction of Radiation Dose

Prediction of radiation dose to organisms from environmental releases of radioactive materials is extremely complex, yet such predictions are required for environmental reports and impact statements. The steps in the predictive process include: determination of source terms; atmospheric and aqueous dispersion and deposition; absorption and uptake by plants; ingestion and inhalation by animals and man; retention and distribution of radionuclides in the body; concentrations in critical organs; and finally, calculation of dose. Each step can involve complex equations with numerous parameters in each. Very few of the parameters are constant over the wide range of circumstances encountered at uranium mines and mills. Because of these complexities, there is usually a considerable degree of uncertainty associated with dose prediction. Predictive models are still being developed.

Source terms are usually predicted from actual measurements at operating facilities or from theoretical calculations. Emanation rates of radon can be estimated on the basis of theoretical models (Kraner et al., 1964; Tanner, 1964) and/or empirical relationships (Schiager, 1974). Rates of particulate suspension by wind can also be estimated in some cases from the literature. Helpful references include Healy and Fuquay (1958); Mills, Dahlman and Olson (1974); and several papers in the volume edited by Englemann and Sehmel (1976). The problems of estimating seepage of radionuclide-bearing liquids into the ground and subsequent migration of the material are discussed by Sears et al. (1975).

Atmospheric dispersion estimates have almost exclusively employed Gaussian plume models with minor modifications to these models. More recent modifications and applications are presented by Slade (1968), Smith (1968), and Turner (1970). The purpose of the dispersion calculations is to predict the concentrations of radionuclides in air at specific locations relative to a given source. With appropriate meteorological data, atmospheric dispersion calculations can be applied with reasonable precision at all sites, excepting those in complex, rugged terrain.

Estimating dispersion of radionuclides in surface waters depends on mixing, turbulence and flow. These are site-specific and depend upon the geometry and nature of the channel or basin. Radionuclides in water are most likely to enter the food chain by direct ingestion or sorption by aquatic organisms. In the case of direct ingestion, the relationships between water concentrations, human body burdens, and radiation doses are thoroughly tabulated in ICRP (1960). Limited data on the relationships between water concentrations of naturally occurring radionuclides and concentrations in the tissues of aquatic organisms are available (Polikarpov, 1966; IAEA, 1976). Such data can be applied with caution to aquatic ecosystems in general, so long as the magnitudes of uncertainty and their causes are understood.

Passage of the naturally occurring radionuclides through food chains also involves many complexities. Some helpful publications are available for radiological impact assessment. Some of the basic models which permit the calculation of tissue burdens from intake and retention data are outlined in ICRP (1960). Such models are applicable to plants, animals and humans, providing the appropriate kinds of parameters and accurate parameter values can be located. While there is generally a lack of information on parameters appropriate to organisms around uranium mines and mills, useful data includes Osburn, 1965; Russell and Smith, 1966; NAS, 1973; Eisenbud, 1973; Cannon, 1952; Gopal-Ayengar, 1962; Garner, 1972; Hill, 1960; and Blanchard, 1967.

When concentrations of radionuclides in the biological tissues have been calculated, the resulting radiation dose may be calculated. Dose, measured in rads or preferably dose equivalent measured in rems, is the common denominator used to describe the effective amount of radiation energy absorbed by critical tissues. These dose units are used as the fundamental predictors of biological damage or risk. Doses received by various internally deposited radionuclides, as well as those from external irradiation, can be summed in order to estimate total dose. Doses are expressed as a rate (that is, rads/year; rems/year) or as a time-integrated dose commitment (that is, rads or rems). Methods of calculating dose are outlined in several publications (ICRP, 1960; Hine and Brownell, 1956; and Morgan and Turner, 1967).

A-4
Radiation Dose Rates and their Significance

The radiological impact of uranium mining and milling is measured by the radiation doses received by populations. The calculated dose is proportional to the concentration of radioactivity and the average residence time of the radioactivity in biological tissue. This dose is termed "dose commitment" or the total dose integrated over the life time of the organism.

Radiation dose rates and dose commitments calculated for all non-human segments of the ecosystem are normally averages for the populations involved, while those calculated for humans are worst possible cases for the individuals involved. This practice is followed because concern for human risk is expressed in relation to individuals and is much more conservative than concern expressed at the population level. The proper dose unit is a multiple of the rem, which is often also termed the dose equivalent. If human population doses are calculated, the proper unit is man-rems. This is the average dose to the human population at risk multiplied by the total number in the population. Expressed this way the value has relevance to the risk of genetic and somatic effects which can only be evidenced in populations.

Direct external radiation doses to humans are by gamma-rays from radionuclides in mill tailings or contaminated local soils. Estimates of radiation exposure rates from radionuclides uniformly distributed in soil are provided in Table A-1. Gamma-ray radiation doses are significant for the whole-body and/or the gonads and may be calculated easily from the measured exposure rates ($\dot{X}$) as:

$$\boxed{\text{DOSE RATE}\left(\frac{\mu\text{rem}}{\text{hr}}\right) = 0.87\ \dot{X}\ \left(\frac{\mu\text{R}}{\text{hr}}\right)}$$

Sears et al. (1975) measured exposure rates over several tailings piles and found the values to average close to 900 microroentgens per hour (μR/hr). Background exposure rates in the environs of typical uranium mining or milling operations generally average about 20 μR/hr. Gamma-ray exposures from tailings can be reduced to natural background levels by covering the tailings with approximately three feet of earth.

Internal dose is received from ^{222}Rn emanating from tailings and from other radionuclides. The critical organ is the lung due to inhalation of radon daughters. Radon emanation is a function of the radium concentration, material porosity, atmospheric pressure, soil moisture, and inert cover. The majority of the lung dose is due to the daughters of ^{222}Rn decay. Sears et al. (1975) have shown that the major contribution to lung dose from radon and its daughters is the tailings pile and not the operating mill. The maximum daughter-product concentration will occur just beyond the edge of the tailings pile in the downwind direction.

Dose to the lung from inhalation of other suspended radionuclides as well as internal organ dose from food chain transfer of radionuclides dispersed in the local environment must also be considered. For "worst possible" dose calculations an individual is considered to live on the site boundary of the mill within the prevailing wind direction from the tailings pile. Sears et al. (1975) have calculated annual dose rates to the whole-body and critical organs of individuals for such cases. Tables A-2 and A-3 are from their publication and are given for model mills in New Mexico or Wyoming for either acid leach followed by solvent extraction or for alkaline leach processes. These are "worst possible" cases and assume the individuals raise their entire food supply locally. There are climatological differences, such as wind speed, that produce the differences between the New

	Exposure Rate/Radionuclide Concentration[a]	
Radionuclide	$\mu R\ hr^{-1}/pCi\ g^{-1}$	$\mu R\ hr^{-1}$/indicated concentration
^{266}Ra + daughters	1.80	$0.61/0.358 \times 10^{-6}\ \mu g\ g^{-1}$ Ra[b]
^{214}Pb	0.20	$0.70/0.358 \times 10^{-6}\ \mu g\ g^{-1}$ Ra[b]
^{214}Bi	1.60	$0.54/0.358 \times 10^{-6}\ \mu g\ g^{-1}$ Ra[b]
^{238}U + daughters	1.82	$0.62/\mu g\ g^{-1}\ {}^{238}U$

[a] One meter above ground; R=Roentgen

[b] Concentration of ^{226}Ra in equilibrium with 1 g $g^{-1}\ {}^{238}U$.

SOURCE: Adapted from NCRP (1976).

Table A-1
Calculated Exposure Rates for Radionuclides Uniformly Distributed in Soil

MILL PROCESSES AND TAILINGS COMBINED

	Solvent Extraction Process (mrem)			Alkaline Leach Process (mrem)		
	Mill	Tailings	Total	Mill	Tailings	Total
Total Body	20.2	16.6	36.8	25.3	16.1	41.4
Bone	232.4	168.0	400.4	265.5	166.3	431.8
Liver	23.6	19.4	43.0	28.3	18.9	47.2
Kidney	40.1	27.0	67.1	40.9	27.1	68.0
Spleen	23.5	21.6	45.1	29.4	20.8	50.2
Lung	29.3	60.4	89.7	35.2	84.9	120.1

[a] Individual is 0.5 miles from the mill during the twentieth year of operation when tailings cover maximum area, assuming 100 per cent of the food is produced locally. The doses are the sum of the doses from airborne particulates and ^{222}Rn gas from operating mill and the active tailings area.

SOURCE: Adapted from Sears et al (1975)

Table A-2
Total Maximum Annual Radiation Dose to Individuals from an Operating Mill in New Mexico

MILL PROCESSES AND TAILINGS COMBINED

	Solvent Extraction Process (mrem)			Alkaline Leach Process (mrem)		
	Mill	Tailings	Total	Mill	Tailings	Total
Total Body	16.5	44.4	60.9	20.6	81.6	102.2
Bone	189.4	447.9	637.3	215.6	841.5	1057.1
Liver	19.1	51.7	70.8	23.0	95.6	118.6
Kidney	32.5	71.9	104.4	33.2	137.3	170.5
Spleen	19.3	57.7	77.0	23.7	105.2	128.9
Lung	23.6	50.8	74.4	28.4	100.5	128.9

[a] Individual is 0.5 miles from the mill during the twentieth year of operation when tailings cover maximum area, assuming 100 per cent of the food is produced locally. The doses are the sum of the doses from airborne particulates and ^{222}Rn gas from operating mill and the active tailings area.

SOURCE: Adapted from Sears *et al* (1975)

Table A-3

Total Maximum Annual Radiation Dose to Individuals from an Operating Mill in Wyoming

Mexico and the Wyoming cases. From these tables, bone is observed to be the critical organ, ^{226}Ra is the limiting radionuclide, and drinking water and the milk food-chain are the critical environmental pathways.

For comparison, predicted doses to individuals who could or do reside at various locations in the vicinity of two Wyoming uranium projects are presented in Tables A-4 and A-5. Table A-4 is from a project that began recently, and Table A-5 is from a proposed project. The predicted radiation doses are based on conservative assumptions by overstating the exposure. The radiation dose depends on the distance and direction from the source. The estimates are calculated using the mine and mill site characteristics, mill equipment performance, and the actual pathways in the vicinity of the projects.

Radiation dose may also be calculated for all other non-human components of the local ecosystems. Wildlife and livestock have nearly identical radiation sensitivities as humans, and it is generally thought that if radioactive effluents are controlled to meet human protection standards, then animal biological effects will be of no concern. Plants and lower forms of animal life are much more radiation resistant than higher forms. Table A-6 from Whicker and Fraley (1974) shows that plant communities are in general radiation resistant. Those plant communities found near uranium milling operations in the western U.S. would not be expected to show any radiation effects.

From calculated human doses, the expected biological effect or risk may also be directly calculated. Two publications are sources for the calculation procedures (UNSCEAR, 1972; NAS/NRC, 1972). The latter publication (called the BEIR report) has expressed the overall risk of radiation dose in terms of genetic and somatic effects. If large populations could be exposed, the risk of genetic effects must be considered. The BEIR report states that between 5 and 50 percent of all ill health is due to genetic defects and estimates that 170 mrem/year to a large population would increase the overall incidence of ill health by 5 percent. Again, the increased incidence is thought to be directly proportional to the additional dose.

Since the number of persons that might be exposed as a result of mining and milling operations is relatively small, the appropriate risk is not genetic effects in a large population but somatic effects to the individuals involved. Cancer induction is generally assumed to be the most sensitive measure of somatic effects, and the BEIR report predicts that an additional exposure of 170 mrem/year to the U.S. population would result in an increase "of about 2% in the spontaneous cancer death rate which is an increase of about 0.3% in the overall death rate from all causes." The risk to any individual per unit radiation dose is expected to be the same. The risk is also directly proportional to the radiation dose, and direct extrapolations to the doses calculated for uranium mining and milling may be made.

			Exposure[a] (mrem/year)			
Location	Distance From Source (meters)	Sector Affected	Whole Body	Kidneys	Lungs	Bone
Point of maximum ground-level concentrations off site:	2000	E	<0.01	1.1	27.5	4.8
Site boundary in the direction of the prevailing wind:	1800 (min)[b] 2500 (max)[c]	NE	<0.01	1.2	23.0	5.2
Site boundary nearest the sources of emission:	1100	W	<0.01	1.5	28.0	6.5
Nearest residence in the direction of the prevailing wind (Carson Ranch)	10,500	NE	<0.01	approx. 0.05	approx. 1.30	approx. 0.23

[a] Based on 50 year dose commitments. To determine total annual exposure, the accumulated dose can effectively be divided by 50.

[b] The shortest distance to a site boundary within the affected sector.

[c] The greatest distance to a site boundary within the affected sector.

SOURCE: Rocky Mountain Energy, 1975

Table A-4
Radiation Dose Commitment to Individuals from the Bear Creek Project

Location	Exposure Pathway	Whole Body	Bone	Lung	Bronchial Epithelium
Bairoil, 35 km NE	Inhalation[b]	2.3×10^{-4}	4.9×10^{-3}	3.0×10^{-2}	1.48
	External	1.9×10^{-3}	2.2×10^{-3}	1.8×10^{-3}	
	Subtotal	2.1×10^{-3}	7.1×10^{-3}	3.2×10^{-2}	
	Ingestion	4.5×10^{-3}	5.7×10^{-2}	4.5×10^{-3}	
	Total	6.6×10^{-3}	6.4×10^{-2}	3.6×10^{-2}	1.48
Property boundary, 2.5 km NE	Inhalation	2.6×10^{-2}	5.7×10^{-1}	3.2	62.5
	External	8.8×10^{-2}	1.0×10^{-1}	8.1×10^{-2}	
	Subtotal	1.2×10^{-1}	6.7×10^{-1}	3.3	62.5
	Ingestion	4.5×10^{-3}	5.7×10^{-2}	4.5×10^{-3}	
	Total	1.2×10^{-1}	7.3×10^{-1}	3.3	62.5

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[a] Doses integrated over a 50-year period from one year of inhalation or ingestion.

[b] Doses to whole body, lung and bone are those resulting from inhalation of particulates of U-238, U-234, Th-230, Ra-226, and Pb-210. The doses to the bronchial epithelium are those resulting from inhalation of radon daughters.

SOURCE: NRC, NUREG, 0403, December, 1977

Table A-5

Radiation Dose Commitments to Individuals (mrem/yr) for the Sweetwater Project

	Exposures (kR) to Produce		
Community Type	Minor Effects	Intermediate Effects	Severe Effects
Coniferous Forest	0.1-1	1-2	2
Deciduous Forest	1-5	5-10	10
Shrub	1-5	5-20	20
Tropical Rain Forest	5-10	10-40	40
Rock Outcrop (herbaceous)	8-10	10-40	40
Old Fields (herbaceous)	3-10	10-100	100
Grassland	8-10	10-100	100
Moss-lichen	10-50	50-500	500

[a] Short-term exposures range from about 8 to 10 days, according to the literature from which this table was derived. Exposures might be reduced by factors of 2 to 4 for acute or fallout-decay irradiation.

SOURCE: Adapted from Whicker and Fraley (1974).

Table A-6

Estimated Short-Term Radiation Exposures Required to Damage Various Plant Communities

Source	Average Dose Rate* (mrem/yr)
Environmental	
Natural	102
Global Fallout	4
Nuclear Power	0.003
Subtotal	106
Medical	
Diagnostic	72**
Radiopharmaceuticals	1
Subtotal	73
Occupational	0.8
Miscellaneous	2
TOTAL	182

*Note: The numbers shown are average values only. For given segments of the population, dose rates considerably greater than these may be experienced.

**Based on the abdominal dose.

SOURCE: Whicker and Johnson, 1978

Table A-7

Summary of Estimates of Annual Whole-Body Dose Rates in the United States (1970)

	Dose Rates (mrad y^{-1})		
Source of Irradiation	Gonads	Bone-lining Cells	Bone Marrow
External irradiation			
Cosmic rays: ionizing component	28	28	28
neutron component	0.35	0.35	0.35
Terrestrial radiation (including air)	44	44	44
Internal irradiation			
^{3}H	0.001	0.001	0.001
^{14}C	0.7	0.8	0.7
^{40}K	19	15	15
^{87}Rb	0.3	0.6	0.6
^{210}Po	0.6	1.6	0.3
^{220}Rn	0.003	0.05	0.05
^{222}Rn	0.07	0.08	0.08
^{226}Ra	0.02	0.6	0.1
^{228}Ra	0.03	0.8	0.1
^{238}U	0.03	0.3	0.06
ROUNDED TOTAL	93	92	89

SOURCE: Whicker and Johnson, 1978

Table A-8

Dose Rates Due to Internal and External Irradiation from Natural Sources in "Normal" Areas

From inspecting the data in Tables A-2 through A-5 it is seen that the BEIR report predictions are based on an exposure which approximates "worst case" conditions which are orders of magnitude higher than predicted for the general population in the vicinity of an operating facility. Although such predictions are useful in setting standards to protect the public, they are not particularly meaningful to local populations who wish to assess the "real world" risk of siting uranium processing facilities near their communities. The doses to the average individual in the vicinity of a model uranium mill has been estimated at .045 mrem/yr (EPA, 1977). Therefore, the actual risk to populations is probably less than predicted above by a factor of several 1000, assuming a linear relationship between dose and health effects.

Additional perspective to the risk of radiation from uranium production facilities is provided by comparing that dose increment to the dose from natural radiation background, although background radiation must be qualified since it is variable. The cosmic ray component of background dose approximately doubles with every mile of altitude increase from sea level to about 20,000 feet. The contribution from natural gamma-ray emitters in the earth's crust also, of course, varies. A description of background radiation whole body gamma dose should include terrestrial dose equivalent (DE) and cosmic DE. The cosmic DE has two components, an ionizing one and a neutron one. The increased radium and thorium concentrations in the western states significantly increase the terrestrial dose. As a result the annual background dose in the western states probably averages over 200 mrem/year (Whicker and Johnson, 1978). Background is measured during the preoperational phase of radiological monitoring and should be used when comparing the doses calculated for mining and milling operations. Tables A-7 and A-8 present estimates of dose rates to U.S. inhabitants.

Another way of considering the biological effects of radiation dose is to discuss life-span shortening of human populations. It is generally thought that life-span shortening is an integration of all radiation effects which are non-specific for low level chronic radiation. The consensus is that a life-span shortening of 1 day per total accumulated dose of 1 rem is a conservative quantitative measure of human life-span shortening from ionizing radiation (Whicker and Johnson, 1978). Again, assuming an average individual dose from a uranium mill of 0.045 mrem/yr, an accumulated dose of 1 mrem would not be received in a lifetime.

CHAPTER 5

Socioeconomic Considerations

Socioeconomic impacts can be positive, negative, or more commonly, a combination of both. Positive impacts frequently include expanded employment and business opportunities, enlarged local tax bases, and arrested decline in some rural areas. Negative impacts may include shortages in public facilities, shortages or inflated prices for housing and privately supplied goods and services, and the emergence of new types of social and political frictions. The potential for negative impacts arises because most energy reserves are in relatively isolated areas where local communities may not have the expertise, the growth management institutions, or the financial resources necessary to accommodate rapid economic growth without major disruptions.

In general, neither the opportunities nor the problems presented by uranium developments are as significant as those presented by other new energy developments, such as coal mines, synthetic fuels facilities, or power plants, because uranium mines and mills typically have fewer employees. However, the opportunities may be enhanced and many of the negative impacts avoided or mitigated if growth is anticipated and public and private sector decision makers cooperate in developing responses.

Based on analysis of a number of uranium and other energy development projects, impacts fall into the following categories:

- DIRECT IMPACTS ON EMPLOYMENT AND INCOME - The introduction of a new mine or mill means new jobs, usually at higher than average wages.
- INDIRECT AND INDUCED IMPACTS ON EMPLOYMENT AND INCOME Mines, mills, and their employees make new demands for local goods and services and spend a portion of their incomes locally.
- POPULATION CHANGES - There may or may not be significant numbers of newcomers to the community.
- PUBLIC SERVICES AND PUBLIC FINANCE - Tax revenues will increase, but so will demands for public facilities and services.
- HOUSING AND COMMERCIAL DEVELOPMENT - Demand for private facilities and services also increases; if local entrepreneurs do not respond, shortages and inflation will result.
- SOCIOCULTURAL AND POLITICAL CHANGE - The introduction of large numbers of newcomers may produce changes in both formal and informal relationships.
- OTHER POTENTIAL CONFLICTS - These may include competition between regulatory agencies for authority, competition among alternative users of land (e.g., recreationists vs. mining interests), or competition for local labor.

Because of the complex interaction between uranium development projects and their host communities, there is no universal model to predict socioeconomic impacts. Even in cases where models exist, the state of the art in forecasting is not precise. Some degree of uncertainty concerning the future is unavoidable. On the other hand, in contrast to certain impacts to the physical environment from uranium development, most adverse socioeconomic impacts are relatively easy to mitigate by institutional means. Accordingly, one key to harmonious development of uranium resources is early contingency planning by both the developer and the host community, followed by an impacts-monitoring program once development gets under way.

Socioeconomic impacts depend on the characteristics of the host community, the region, and of the project itself. The effects of all growth near the host community should be included in the analysis of appropriate responses. Frequently, the impacts of a single project are relatively negligible, while the impacts of all new stimuli to the local economy, including one or more mines and/or mills, are quite large. Table 5-1 summarizes important factors in each category and will serve as a convenient checklist for administrators and planners.

The following discussion provides a more detailed description of impacts as well as other sources of information and possible industry and government responses for each impact category. In some instances, more text is devoted to problems than to opportunities; this is not done because the problems will necessarily outweigh the opportunities, but because with proper attention and planning, most problems can be avoided or at least alleviated.

Impact Category	Opportunities/Problems	Related Mine/Mill Characteristics	Related Community/Regional Characteristics
(1) Direct Impacts on Employment and Income	• Communities with high unemployment will receive needed new jobs. • Increased economic activity may bring increased per capita incomes. • Substantial growth of limited duration (e.g., depleting reserves) or uncertain duration (e.g., as a consequence of volatility in uranium prices) may set the community up for a bust to follow the boom. • The rate of growth and/or uncertainty concerning the timing or duration of uranium development may cause stresses or breakdowns in other systems.	• Phasing of construction and operating employment. • Production levels. • Marginal versus clearly economic ore grades. • Local hiring versus the number of in-migrants. • Labor requirement for highly specialized skills. • Recruitment efforts of the uranium and construction companies and/or union policies. • Availability of on-the-job training program.	• Degree of regional unemployment and underemployment. • Availability of specialized skills and existence of local union hall. • Relationship of local salaries to construction and uranium project salaries. • Presence and effectiveness at local vocational, technical or industry training programs. • Commuting distance to work site.
(2) Indirect and Induced Impacts on Employment and Income	• Increases in local purchasing power may ultimately lead to the availability of a wider range of private goods and services. • Increased growth may lead to new local entrepreneurial opportunities. • Local labor costs may be forced upward by competition from the incoming uranium industry, producing local inflation. Local businesses may not be able to compete with higher industry wages. Reduced availability of labor degrades quality of service.	• Distance to local communities. • Extent of local versus non-local purchasing. • Distance to local communities. • Settlement patterns of employees.	• Distance to regional trade center. • Present level of diversification. • Present local salary levels. • Degree of regional unemployment and underemployment. • Likelihood of local versus non-local purchases by household and service sectors. • Availability and capital for financing business ventures.
(3) Population Changes	• Fewer of the community's young people may leave because they perceive a lack of economic opportunity. • Population growth may overtax existing public and private facilities and services.	• Employment totals. • Characteristics of incoming work force and families.	• Present availability of public and private facilities and services, housing and other amenities. • Travel time to place of employment.

SOURCE: DRI

Table 5-1
Factors Influencing the Occurrence of Socioeconomic Impacts

Impact Category	Opportunities/Problems	Related Mine/Mill Characteristics	Related Community/Regional Characteristics
(4) Public Services and Public Finance	• Uranium developments lead to large increases in the local property tax base. Ultimately, this may provide for reductions in tax rates and/or increases in the level of public services. • During the initial development period, tax base growth may lag far behind population growth. Local jurisdictions may also encounter institutional constraints in attempting to borrow funds to finance development. The result may be increases in local tax rates and/or degradation in public services for several years. • Public finance problems prevent timely provision of services and facilities. • Dissatisfaction of workers and their families with their quality of life may lead to alienation and to high labor turnover rates, low productivity and higher production costs. • Dissatisfaction with reductions in the quality of life may lead to increased opposition to future energy developments by residents and state and local governments.	• Phasing of construction and operating employment. • Timing of assessed valuation increases. • Jurisdiction(s) receiving new assessed valuation versus those receiving population.	• Local revenue structure. • Institutional constraints on public borrowing. • Jurisdiction(s) receiving population increases versus those receiving increased assessed valuation. • Availability of state mechanisms for impact assistance. • Local cost factors for supplying services and facilities. • Local expertise in obtaining outside financing and in federal/state grantsmanship.
(5) Housing and Commercial Development	• Private investors, particularly housing developers and lenders, may not have the ability or adequate incentive to keep up with growth in the economy. Shortages and local inflation are the result.	• Salaries of incoming workers. • Housing preferences of incoming workers. • Degree of local versus non-local purchasing. • Timing and duration of uranium development.	• Availability and cost of factors of production. • Present diversity of local economy. • Constraints on borrowing development capital, obtaining mortgages. • Availability, cost, and quality of existing housing. • Local entrepreneurial ability.

SOURCE: DRI

Table 5-1 (continued)
Factors Influencing the Occurrence of Socioeconomic Impacts

Impact Category	Opportunities/Problems	Related Mine/Mill Characteristics	Related Community/Regional Characteristics
(6) Sociocultural and Political Changes	• Newcomers may bring assets (education, managerial skills) which can benefit the community. • Values conflicts may arise between old-time and newcomer cultures. • Old-timers may experience a loss of intimacy and "small town feeling" as the community grows. • Old-timers may lose political control of their community. • Housing shortages, shortages or degradation in the quality of other privately and publicly financed goods and services, and rural sprawl settlement patterns all tend to produce more alienation of residents. This alienation also further increases the likelihood that old-timers will resent the changes in life-styles and that values conflicts will arise. • Local governments' inability to handle their own housing and public finance problems may bring more state and federal intervention into community affairs. This intervention may be resented by local residents and officials.	• Social characteristics of incoming work force. • Expectations of quality of life.	• Existing social, political and cultural structures. • Settlement patterns encouraged by community. • Efforts to assimilate newcomers.
(7) Other Potential Conflicts	• Low paying jobs in public and private sector cannot compete for labor. • Competition for land may bid up prices. Land uses change (marginal agriculture land taken out of production). • Competing regulatory authorities may increase uncertainty concerning the occurrence and timing of development and thus hinder efforts to mitigate impacts.	• Wage rates of construction and uranium industry. • Location of development and characteristics of surrounding area.	• Wage rates and extent of underemployment in other local sectors. • Existence of planning and zoning prohibits some uses. • Applicable state regulatory structures.

SOURCE: DRI

Table 5-1 (continued)
Factors Influencing the Occurrence of Socioeconomic Impacts

5.1
Direct Impacts on Employment and Income

Changes in employment and income as a result of uranium-related development cause direct impacts on the local and regional economy. These impacts are usually viewed as positive by the host community. The benefits of these changes can be increased and other indirect negative impacts reduced if uranium projects can hire local residents; for instance, local unemployment can be reduced and per capita income increased, thereby reducing the negative impact of requiring new schools before the tax base is available to pay for them. Generally, total direct impacts on employment and income will be a function of the following:

- The number of facilities being built in the same area. When several projects occur in the same region, each succeeding project will rely more on outsiders for employees.
- The phasing of development of multiple facilities. Construction-related employment can often be made much more stable if projects are timed so that essentially the same work force is employed for each project.
- The level of effort by the mine or mill to hire local residents.
- The labor requirement for highly specialized skills. Local labor pools in rural areas are not often able to provide workers with highly specialized or technical expertise.
- The degree of regional unemployment. Improper functioning of formal or informal information networks on employment opportunities may lead to the number of newcomers exceeding the number of new jobs, actually increasing unemployment.

5.1.1
Employment

The three most common analytical approaches used to estimate the number of local employees versus newcomers are (1) to assume all employees are newcomers, (2) to extrapolate from the ratio of newcomers found in similar projects, and (3) to analyze the local market's capabilities to meet project needs. To assume that all new employees will be newcomers is a conservative approach, often taken where there is little available data. It is based on the premise that local hirees will be vacating jobs that will be filled in turn by newcomers. The extrapolation approach is to use the results of surveys taken in previous energy-impacted areas. The market-analysis approach is to analyze the skills of the local labor force and relate them to the needs of the mine or mill.

In analyzing direct employment, a distinction is made between construction and permanent workers. This distinction is important in both assessing long-term impacts and in considering mitigation measures. Since construction workers tend to be temporary, area populations may fall as rapidly at the end of construction as they rose at the beginning. Thus classrooms and utilities systems built to handle the increased population will not be efficiently used, but the remaining residents will still be responsible for the debt incurred for construction of such facilities.

Project	Start-up Date	Normal Capacity	Construction Time	Peak Construction Force	Total Operating Force*	Union/ Non-Union
Mines						
Surface	mid 1970's	1,700 TPD	7 months	141	141	non-union
Surface	mid 1950's	varies according to grade	2 years	NA	455	union
Surface	early 1970's	2,000 TPD	2-1/2 years (initially scrapper operation)	NA	220	non-union
Underground	projected early 1980's	4,500 TPD	10 years for all construction to be complete	300	750	NA
Underground	early 1970's	1,100 TPD	2-1/2 years	60	164	mixed
Underground	early 1970's	600 TPD	4-1/2 years for all construction to be complete	NA	180	union
Mills						
Mill (acid-leach)	mid 1950's expanding late 1970's	3,000 TPD expanding to 6,000 TPD	11 months for expansion	600	421	union
Mill (carbonate-leach)	early 1970's	750 TPD	20 months	60 (all surface buildings)	83	mixed
Mill (acid-leach & akaline-leach)	mid 1950's converted mid 1970's	1,200 TPD	4 years for entire conversion	120 (conversion)	185	non-union
Mill (acid-leach)	mid 1970's	1,000 TPD	1 year (includes 2 month delay for NRC Statement)	70	51	non-union

*Includes office and maintenance personnel.

SOURCE: DRI interviews with mine and mill operators.

Table 5-2

Estimates of Work Forces for Selected Uranium Mines and Mills

Examples of the number of operation and construction employees and construction times for various types of uranium mines and mills are shown in Table 5-2. These vary widely from project to project, depending on such factors as:

- Geologic conditions
- The resultant mine and mill plans and engineering specifications
- The construction techniques used (e.g., extent of prefabricated subsystems)
- The geographic location (including the consideration of established transportation systems and distance to regional trade centers)
- The existence of regional union labor pools and types of skills represented
- The discretion allowed project managers to make trade-offs to use smaller construction forces over longer periods of time

The prime contractor for the construction project and operating companies for mine and mill facilities are the best sources for obtaining data on employment. Where an employer's data are unavailable, general figures on worker productivity may be used in combination with estimates of mine output. Table 5-3 gives the average worker-productivity in the U.S. for underground and open-pit mines. As indicated, it is important to use recent estimates because productivity has fluctuated sharply with technological innovations and changes in mine safety requirements.

Tons Per Man-Shift

	Underground Mines			Open Pit Mines		
	Miners	Service and Support	Total	Miners	Service and Support	Total
1969	7.8	18.0	5.4	16.6	22.1	9.5
1970	8.5	18.6	5.8	19.1	27.1	11.3
1971	8.1	18.1	5.6	21.7	27.8	12.2
1972	8.6	19.4	6.0	22.7	32.0	13.3
1973	8.2	15.3	5.4	28.0	38.6	16.2
1974	8.3	19.0	5.8	30.7	35.3	16.4
1975	6.4	10.6	4.0	26.1	29.6	13.9
1976	7.5	9.0	4.1	21.8	30.6	12.7

Source: ERDA, January 1976.

Table 5-3
Changes in Worker Productivity

5.1.2
Income

Wage rates for construction and operating employees will normally be considerably higher than those of the local service and public employees, even allowing for variations such as region, skills involved and union pay scales. Uranium industry employees can further augment their base pay by overtime, bonuses and other incentives based on individual productivity. As a result, it is frequently possible for an experienced miner taking advantage of all offered incentives to make $30,000 per year. Typical wages received by employees in various industries are given in

Table 5-4. Wage differentials for different skills are illustrated in Table 5-5.

Potential actions to enhance opportunities and/or mitigate problems include:

Community actions

- Vocational training programs for local residents
- Accurate job status publicity (to prevent in-migration of workers in excess of available jobs)

Industry actions

- Local recruitment efforts by both construction contractors and operators

For more information see:

General sources on worker characteristics

- University of Wyoming. Agricutural Experiment Station. Profile of a Rural Area Work Force: The Wyoming Uranium Industry. Research Journal 79, Laramie: January 1974.
- Uhlmann, Julie M., et al. A Study of Two Wyoming Communities Undergoing the Initial Effects of Energy Resource Development in the Powder River Basin: Buffalo and Douglas, Wyoming—1975. Laramie: University of Wyoming, 1976.
- Mountain West Research, Inc. Construction Worker Profile. Washington, D.C.: Old West Regional Commission, 1976.

Other sources

- Environmental Impact Statements for specific facilities (e.g., Rocky Mountain Energy Company, Bear Creek facility, Converse County, Wyoming; Minerals Exploration Co., Red Desert facility, Sweetwater County, Wyoming; Rio Algom, La Sal facility, San Juan County, Utah)
- State and regional employment offices
- Unions

Occupation	Wyoming	New Mexico	Utah
Uranium Industry			
Mine	$1,250 - 1,833	$1,000 - 1,833	$1,500 - 1,833
Mill	$1,250 - 1,667	$1,000 - 1,500	$1,000 - 1,500
Carpenter (union)	$1,600 - 1,900	$1,730 - 1,880	-------
(non-union)	$ 920 - 1,070	$ 870 - 1,020	$ 700 - 850
Police Officer	$ 780 - 930	$ 800 - 1,100	$ 700 - 850
Fireman	--------	$ 600 - 800	$ 680 - 830
City Laborer	$ 700 - 850	$ 550 - 650	$ 520 - 670
City Mechanic	$1,190 - 1,340	$ 800 - 900	$ 870 - 1,020
Clerk-Typist (steno)	$ 500 - 650	$ 520 - 670	$ 440 - 590
(bookkeeper)	$ 580 - 730	--------	---------
Auto Mechanic	$ 930 - 1,080	$ 800 - 900	$ 660 - 810
Truck Driver (heavy)	$ 840 - 990	$1,130 - 1,280	$ 910 - 1,060
(light)	$ 630 - 780	$ 780 - 930	$ 490 - 640

SOURCE: 1977 State Job Listings.

Table 5-4
Average Monthly Salary Ranges for Selected Areas

Job Category	Industry Average	Mill Average	Mine Average
Junior lab technician, unskilled, beginning secretary	under $10,000	under $10,000	under $10,000
Secretary, entry level, semi-skilled	$10,000-15,000	$10,000-12,000	$10,000-15,000
Skilled draftsmen, operators, miners	$15,000-20,000	$12,000-18,000	$15,000-20,000
Supervisory personnel	$20,000-25,000	$14,000-20,000	$20,000-25,000
Administration	above $25,000	above $20,000	above $25,000

SOURCE: DRI interviews with industry officials in Wyoming, Utah, and New Mexico.

Table 5-5
Examples of Average Wages for Uranium Industry Workers

5.2
Indirect and Induced Impacts on Employment and Income

The direct changes in employment and income associated with uranium development can cause indirect and/or induced changes in virtually every other sector of the local and regional economies. Uranium development may produce indirect changes in other basic industries; for example, increases in uranium-linked industries, such as railroad- and mining-equipment suppliers, may occur. Capital expenditures and salary dollars invested in the local economy by the uranium industry and associated activities increase spending, which leads to induced changes, such as increased purchasing power, economic activity, and supporting (nonbasic) jobs.

Indirect changes are not always positive. For example, agricultural production may decrease because of competition for local labor. This in turn could reduce economic diversity.

5.2.1
Non-Basic Economic Activity

Uranium development also stimulates changes in nonbasic economic activity. In a simple model of a local or regional economy, basic economic activities are those which import purchasing power from outside the region. Nonbasic activities, activities which provide goods and services to households and/or businesses within the region, are considered to be a function of the level of basic economic activities. Nonbasic economic activities include some (but not necessarily all) wholesaling, commercial and financial establishments, some light industries, the local housing industry, and the local public sector.

The extent of indirect or induced impacts in the host community depends upon the following:

- The distance to the nearest regional trade center. Regional trade centers are capable of absorbing a portion of the increased activity due to area resource development without much disruption. Small rural communities are not able to do this.
- The shopping habits of local residents. As an example, Albuquerque is within easy driving distance (all interstate) of Grants, New Mexico, and many residents of Grants drive there to shop. This may tend to reduce the incentive for Grants to greatly expand its businesses.
- Present diversification of the local economy. Many businesses in small rural communities could not handle a sudden, large increase in business. Limited shopping is available, usually consisting of a drug store, small department-type store, a limited item grocery store, etc.

5.2.2
Analytical Approaches

The analytical approaches used most frequently for estimating changes in nonbasic economic activity due to changes in basic economic activity are export-base multipliers and input-output models. Export-base analysis expresses the relationship between basic and nonbasic activities in terms of simple ratios, or multipliers. Multipliers may be calculated using either employment or income data.

Input-output analysis is based on the interrelationships of firms both as purchasers of inputs and as producers of outputs. It provides a means of determining how changes in the output of any industry will affect each sector of the economy. Input-output analysis is a more sophisticated technique than export-base analysis; however, it is used much less frequently in impact assessment. One reason is the cost. Up-to-date input-output tables are frequently unavailable for the area to be studied and are expensive to prepare. The most common approach is the employment multiplier, primarily because of ease of application. Income multipliers may be used almost as easily.

Depending on the local economic and political environment (e.g., present levels of unemployment and underemployment and political attitudes toward growth), the host community may want to maximize or minimize the indirect and induced effects of the proposed development.

Potential actions to enhance opportunities and/or mitigate problems include:

Community actions

- Informal actions (e.g., Chamber of Commerce) to publicize business opportunities

Industry actions

- Maximizing (or minimizing) local purchases of supplies and material
- Encouraging employees to live nearby (or to commute to nearby communities)

For more information see:

More detailed descriptions of analytical techniques

- Miernyk, William H. The Elements of Input-Output Analysis. New York: Random House, 1965.
- Tiebout, Charles M. The Community Economic Base Study. New York: Committee for Economic Development, December 1962.
- Hirsch, W.Z. Urban Economic Analysis. New York: McGraw-Hill, 1973.

Examples of use of these techniques

- Employment Multiplier: Denver Research Institute, University of Denver (e.g., Gilmore, et al., Socioeconomic Analysis Appropriate for an Environmental Impact Statement for a Uranium Mine-Mill Complex at Bear Creek, Wyoming).
- Income Multiplier: Arizona State University, Department of Economics (e.g., Chalmers, James A. and E.J. Anderson [Mountain West Research, Inc.]. Economic/Demographic Assessment Manual. Denver: Bureau of Reclamation, November 1977).
- Input-Output: University of New Mexico, Bureau of Business and Economic Research, Albuquerque, New Mexico.

5.3
Population Changes

Estimates of population growth related to development are based on employment projections. First, employment estimates are adjusted to account for any expected increases in jobs held by local residents (e.g., changes in unemployment levels and/or labor participation rates). The resulting estimates, that is jobs to be taken by outsiders, are then translated into estimates of population growth using one of the following three techniques:

- Labor participation – The ratio of labor force members to population. This technique assumes that this ratio is the same as the regional average.
- Worker characteristics – The characteristics of the work force are assumed to be similar to those found in surveys at previous project sites. Singles and families are projected separately using such variables as head of household, family size, and number of children. Different variables are normally used for construction and operating employees.
- Cohort survival – Births, deaths, and net migration are projected separately for each age and sex cohort of the population at periodic intervals. Additional assumptions must be made concerning the age and sex distribution of newcomers.

While the cohort survival technique provides the most detailed results, it is the most time consuming and requires the most data and initial assumptions. This added detail may be appropriate in special situations such as where there is concern over the size of the elderly population or where mines or mills are located near Indian reservations.

5.3.1
Settlement Patterns

In addition to the magnitude and timing, the geographic distribution of income and employment effects among local communities and taxing jurisdictions is important. Possible settlement patterns are influenced by the following:

- Location of the new facility
- Travel time to the point of new employment
- Present availability and quality of public amenities (e.g., utilities, schools, public services, recreation facilities)
- Present availability and quality of private facilities and services (e.g., shopping and medical care) and presence of employment opportunities for any other wage earners in families
- Present availability and quality of housing
- Announced plans for new housing developments, and public and private facilities and services
- Residential choices of people presently working at or near the point of new employment
- Special incentives (e.g., availability of subsidized housing or special transit systems)

5.3.2
Prediction Techniques

Three of the most commonly used approaches for predicting the geographic distribution of impacts are as follows:

- The gravity model, in which community attractiveness is a function of population mass and distance
- A community weighting approach, which incorporates housing prices and subjective assessments of the community attractiveness
- The Delphi technique, a system for eliciting expert opinion by sequential rounds of questioning

None of these methods have been shown to be particularly accurate predictors of settlement patterns. It may be that the decision process is sufficiently random that no technique is a good predictor. In some instances, it may be better to think of worker settlement patterns as a policy variable rather than something to forecast. Workers might be encouraged to live in the communities where their presence causes the most favorable impacts and the fewest problems.

Potential actions to enhance opportunities and/or mitigate problems include:

Community actions

- Encouragement of housing growth to accomodate types of population desired (e.g., permanent single family units or mobile homes and barracks)
- Use of growth management techniques (e.g., zoning, utility moratoria, higher tap fees) in those areas which would suffer the most adverse impacts

Industry actions

- Recruitment efforts focused on desired types of employees
- Informal encouragement of employees to live in designated areas
- Incentives to employees to live in designated areas (e.g., bus service to mine/mill sites, subsidized housing)

For more information see:

Examples of population analysis techniques

- Labor Participation: Tennessee Valley Authority. Final Environmental Statement Morton Ranch Uranium Mining. Chattanooga, Tennessee: January 1976.
- Worker Characteristics: U.S. Nuclear Regulatory Commission. Draft Environmental Statement Rocky Mountain Energy Company's Bear Creek Project. Washington, D.C.: January 1977.
- Cohort Survival: Wyoming. Department of Economic Planning and Development (DEPAD). The Navajo Nation, Office of Program Development. The Navajo Economic-Demographic Model. Window Rock, Arizona: January 1976. Available from Office of the State Planning Coordinator, Salt Lake City, Utah.

Examples of techniques for analyzing population settlement patterns

- Gravity Models: Chalmers, James A. "The Role of Spatial Relationships in Assessing the Social and Economic Impacts of Large Scale Construction Projects." Natural Resources Journal, April 1977, pp. 209–222.
- Community Weighting: Williams, David, et al. Impacts of the Proposed Peabody Rochelle Coal Mine. Reston, Virginia: USGS, 1978.
- Delphi: Schmitz, Steve, et al. Growth Monitoring System Project Report for State Planning and Management Region XI. Rifle: Colorado West Area Council of Government, 1977.

5.4
Public Services and Public Finance

The development of uranium resources may have major impacts on public finance and public services. Many local jurisdictions hosting uranium development eventually benefit from an increased tax base. In the short run, however, uranium developments in sparsely populated areas may also cause serious public finance problems. When a new development is initiated, the need for public expenditures frequently grows much faster than revenues from existing sources. This is particularly true for city or town governments, since development normally takes place outside corporate limits.

Local officials may confront the following problems:

- Revenue shortfalls (cash flow problems) resulting from the lag times in receipts of increases in revenues and the lead times required to provide new facilities.
- The potential for mismatches between those receiving revenue increases and those confronted with increases in demands for services (uranium development can take place across county, school district or even state lines from where population settles). For example, Grants, in Valencia County, New Mexico, is the home of employees of the Kerr-McGee Ambrosia Lake Mill, the Rancher's Johnny M Mine, and the Gulf Mt. Taylor Mine—all located in McKinley County. Municipalities almost always have these problems, since uranium operations are rarely within corporate limits.
- The high level of risks for local bonding. The timing and duration of uranium developments are subject to uncertainty. Since the tax base depends on their presence, their delay or abandonment imposes a high bond repayment burden on the residual tax base.
- The potential for sharp increases in public operating costs. Salary costs frequently increase due to competition with the new uranium-related jobs.
- The need for new expertise. The financial expertise necessary to be successful in obtaining outside assistance or in obtaining satisfactory arrangements with outside financial institutions or bond markets is frequently not available in small communities.

The revenues and expenditures associated with uranium development must be projected to determine net impacts. Projections should be made at least on an annual basis to reflect concerns over front-end financing and cash flow problems. They should be made separately for each relevant jurisdiction to address the issue of mismatches between those receiving the costs and those receiving the benefits.

5.4.1
Revenues

A close examination of the tax structure of the state where the operations are located is necessary for accurate estimates of public revenues directly related to uranium production. Table 5–6 lists the taxes applicable in the state of Utah. Table 5–7 provides an example of the taxes due from a typical mining operation in Utah. Other states vary greatly from this example. The approach commonly used to project other indirect public revenues includes dividing revenues into sub-categories which can be estimated based on previously derived estimates of increases in real property, production, income and/or population. Estimates of virtually all revenues other than those directly related to uranium development are made on a per capita basis. Some more complex estimating methods involve use of input-output analysis to derive public sector revenues and use of multivariate relationships derived from cross-sectional analysis.

Title & Legal Citation	Year Enacted	Basis of Tax	Rates	Allocation and Use
General Property 59-1-1 to 59-11-16	1849	30% of "reasonable fair cash value"* of real and tangible personal property. Metalliferous mines assessed at $5 an acre plus two times average net proceeds. In addition, machinery and other property of mines assessed at 30% of reasonable fair cash value.	Varies in each city, county and school district. In 1977, total property tax ranged from 46 mills in an unincorporated area of Daggett County to 114.95 in Salt Lake City; state average was 78.59.	School districts, municipalities, counties, and special districts.
Sales and Use 59-15-4 59-16-3	1933	Retail sales or use of tangible personal property, utility services, admissions, meals, general services, hotel, motel, laundry and dry cleaning.	4% of purchase price.	To General Fund.
11-9-4 11-9-6	1959	Local option--county, city.	3/4% of purchase price.	Returned to local unit imposing tax.
11-9-4 11-9-6	1974	Local option—county (only Salt Lake, Weber and Davis Counties).	1/4% of purchase price.	Transit District.
Corporate Franchise 59-13-65	1931	Net income allocable to state; no deduction for federal taxes.	4% of net taxable income. Minimum tax for state banks and corporations is $25.	To Uniform School Fund; distributions to districts under minimum school program.
Unemployment Compensation 35-4-7	1936	Base is the latest average annual wage; this changes every year—currently $9,600.	A range of 1.3% to 3% of covered payroll. Entire tax paid by employer.	To Unemployment Compensation Fund; used to pay unemployment benefits.
Motor Fuel 41-11-6	1923	Gallons of motor fuel sold or used.	9¢ per gallon. (July 1, 1978)	To Highway Construction and Maintenance Fund; used for highway construction and maintenance.
Motor Vehicle Registration 41-1-127	1909	Motorcycles, private autos, house trailers, manufacturers, transporters, dealers, and wreckers—flat fees. Motor vehicles, trailers, and semitrailers used for transportation of passengers or property—unladened weight of vehicle.	Motorcycles and small trailers—$2.50; private autos—$5.00; house trailers--$5.00; commercial vehicles--$7.50 to $585, extra for reflectorized plates—$1.00 per set.	Cities and counties get first $2,000,000 after admin. expense. Balance: 3/4 to cities and counties, 1/4 to State Highway Fund.
Mine Occupation 59-5-67	1937	Gross amount received or gross value of metalliferous ore sold--$50,000 exempt.	1%.	To General Fund.

*"Reasonable fair cash value" is not necessarily current market value. Presently the actual assessment ratio is between 6% to 24% in the extremes, but the state aim is for all property to eventually be assessed at 20% of current market value.

SOURCE: Compiled by the Utah Foundation from the Utah Code Annotated 1953, as amended. Updated based on interviews with the Utah State Tax Commission.

Table 5-6

Examples of Utah Taxes to be Paid by Uranium Mining and Milling Companies

Assumptions:

- Initial investment = $45,000,000 (1977 dollars)
  - Cost of mine = $25,000,000
  - Cost of equipment = $ 1,000,000
- Mine normal capacity = 1,700 TPD
- Mill normal capacity = 1,000 TPD
- Pounds of yellowcake/year = 600,000
- Selling price = $ 40
- Complex is on BLM land
- Estimated taxes for first year of operation (1978)
- Uranium company property and assets are distributed equally between Utah and another state

Property Tax	
Assessed value of mill is 20% of $25,000,000	$ 5,000,000
Assessed value of machinery is 20% of $1,000,000	200,000
Assessed value is 2 times $1,300,000 (net proceeds = gross proceeds minus mining cost and machinery purchased during year)	2,600,000
	$ 7,800,000
Tax rate	60 mills
	$ 468,000
Sales or Use Tax	
$3,000,000 expended annually for mine and mill supplies times 4.75%	$ 142,500
Corporate Franchise Tax	
Net proceeds ($1,300,000) minus 1/3 for depletion allowance (432,900) = $867,100	
$867,100 divided by two (because company equally split between two states) = $433,550	
$433,550 x 4%	$ 17,342
Unemployment Compensation	
Estimate for 210 employees earning $3,816,000 is 2.7% on the first $9,600 paid to each employee during 1978 ($9,600 x 210 = $2,016,000 x 2.7%)	$ 54,432
Mine Occupation Tax	
Gross proceeds ($2,400,000) minus deduction ($50,000) = $2,350,000 x 1%	$ 23,500
TOTAL	$ 705,744

SOURCE: DRI

Table 5-7
Estimated Major Utah Taxes to be Paid by a Hypothetical Uranium Mine-Mill Complex

Another important variable is the revenues mix of local jurisdictions. Jurisdictions which rely heavily on ad valorem taxes are the hardest hit by revenue lags. Sales taxes and tap fees are examples of sources which arrive earlier. Equally important is consideration of the fiscal position of the jurisdiction before development begins. Counties with substantial amounts of other resource production, such as oil, gas, and coal, are in a much better position to address uranium development problems than those with predominantly agricultural tax bases.

5.4.2
Expenditures

A variety of techniques are available for estimating needs for new public expenditures. Two of the most common approaches are the use of national or regional per capita standards and the use of the "best judgment" of local officials responsible for providing the services. No approach is without problems, and a detailed analysis of these issues is necessary before carrying out an expenditure analysis.

Special emphasis should be given to the differences between public facilities and services required by permanent residents and those required by temporary construction workers. This is necessary to avoid overestimating the increases in public expenditures. Needs also vary greatly from community to community. A useful rule of thumb for early planning is that roughly $1,000 per year in new operating expenditures and $5,000 in new capital outlays are required for each new resident if the quality of local services is to be maintained (Moore, 1976). Some capital outlays need to occur one to two years prior to the arrival of the new construction work force.

5.4.3
Public Finance Constraints

With the exception of jurisdictional mismatches, most development-related public finance problems are relatively short-term, lasting from two to seven years. Host communities and other local jurisdictions require either outside capital or a substantial line of credit to get through these critical years. Unfortunately, most experience thus far has been that outside assistance and local borrowing have not been sufficient to prevent a reduction in the level of local services. Local borrowing is inhibited by the following mutually reinforcing set of constraints.

- ACCESS TO INFORMATION – Local officials often do not receive early warning of impending development. Industry is faced with development uncertainty due to such things as litigation and international resource prices.
- ACCESS TO EXPERTISE – Small communities may have little experience in capital improvements programming or other intermediate range budgeting techniques, the bond market or in federal grantsmanship.
- ACCESS TO CAPITAL – Institutional constraints may limit local governments' participation in the bond market. For example, statutory bonding limits range from 10 percent of assessed valuation for school districts to 2 percent for counties in Wyoming.

CONSTRAINTS, Continued

- RISK –The uncertainty of the timing of development and the possibility of abandonment may cause concern that public facilities financed to accommodate growth will not be needed and that bonds will have to be paid out of the existing tax base.
- ABILITY TO PAY – Some local entities may be unable to pay off early years' debt service without large increases in tax rates. Voters may often refuse to pass bond issues even when the need for new facilities is apparent.

Potential actions to enhance opportunities and/or mitigate or avoid these problems include:

Community actions

- Tax base sharing where there is a jurisdictional mismatch (Wyoming has examples of both formal mechanisms— the state's Joint Powers Act—and informal mechanisms— movement of the school district boundary within Converse County)
- Shifts in reliance from taxes with long lead times (e.g., property taxes) to faster revenue sources (e.g., utilities tap fees)
- Extensive use of external assistance programs (e.g., Environmental Protection Agency, Economic Development Administration, state energy impact assistance funds)

Industry actions

- Coordination of scheduling of construction with local officials
- Temporary financial assistance (e.g., planning grants) to particularly needy local governments
- Prepayment of future taxes (only Utah presently has this option)

POTENTIAL ACTIONS, Continued

State actions

- Establishment of energy impact assistance funds with a portion of energy-related revenues
- Provision of local technical assistance in planning, growth management, and grantsmanship
- Establishment of institutions to coordinate assistance and ensure that problems are mitigated (e.g., Wyoming Industrial Siting Council, Wyoming Department of Community Development, New Mexico Energy Resources Council, Colorado Impact Assistance Coordinator, and Texas Energy Advisory Council)

For more information see:

General discussion of fiscal analysis

- Real Estate Research Corporation. Costs of Sprawl. Washington, D.C.: U.S. Government Printing Office, 1974.
- Muller, Thomas and Grace Dawson. The Fiscal Impact of Residential and Commercial Development: A Case Study. Washington, D.C.: The Urban Institute, 1972.
- Gilmore, John, et al. (Denver Research Institute). Impacts of Western Energy Development. Washington, D.C.: The President's Council on Environmental Quality, 1978.

Examples of the use of alternative techniques

- U.S. Nuclear Regulatory Commission. Draft Environmental Statement Rocky Mountain Energy Company's Bear Creek Project. Washington, D.C.: January 1977.
- Combination: Baldwin, Thomas E., et al. A Socioeconomic Assessment of Energy Development in a Small Rural County: Coal Gasification in Mercer County, North Dakota, Vol. II. Argonne National Laboratory, 1976.
- Per capita: Laholm, Arlene G., et al. The Economic Impacts of Construction and Operation of Coyote Station #1 Electrical Generation Plant and Expansion of Coal Handling Facilities at the Beulah Mine of Knife River Coal Company. Denver: Stearns-Roger, Inc., 1976.

MORE INFORMATION, Continued

Discussions of mitigation alternatives

- Briscoe, Maphis, Murray and Lamont, Inc. Action Handbook for Small Communities Facing Rapid Growth. Denver: Environmental Protection Agency, 1978.
- Moore, K.D., et al. (Denver Research Insitute). Mitigating Adverse Socioeconomic Impacts of Energy Development: Present Programs and Mechanisms and Further Policy Options. Washington, D.C.: U.S. Department of Energy, 1977.
- Centaur Management Consultants, Inc. Assistance for Energy Developers: A Negotiating Guide for Small Communities, Washington, D.C.: Energy Research and Development Administration, 1977.

5.5
Housing and Commercial Development

In addition to shortages in public facilities and services, rapid growth can lead to shortages in housing and in commercial development. Housing problems are often the first major sign of population growth impacts. Prices for new construction and for rental units begin to increase as demand overtakes supply. The private business sector of the local economy is not able to keep up with demand either. Financing for expansion of commercial establishments is difficult to obtain or nonexistent; existing businesses are accustomed to operating under stable conditions and may not have the stock or the help to handle increased business. In times of rapid growth, the private sector suffers many of the same problems as the public sector.

5.5.1
Housing

Most assessments of housing impacts consist of an estimate of the increased need for housing. These are usually based on housing surveys done in the area by local lending institutions, realtors or planning agencies. Information collected often includes the number of housing units by type, such as single family, apartments, and mobile homes; types of housing available; price or monthly rental; age of dwelling; and household income levels. However, equal attention should be (and seldom is) given to whether suppliers are likely to provide the needed units and whether buyers are able to pay for them.

The housing needs of construction workers are often temporary. Many workers live in mobile home parks (often bringing their own trailers or campers), rooming houses, or motels for the duration of the construction project. The housing demand of the permanent operating work force is basically a function of:

- the need for housing (normally based on household size)
- preference for different types of units (mobile homes, single family units or apartments)
- income levels and willingness to pay
- ability to secure financing

Although the income levels of most uranium mine and mill employees are high enough to initially qualify them for a mortgage, the uranium-mining industry is known for the mobility of its work force. This can cause difficulty in providing adequate credit and employment histories for loan applications. Conservative lending institutions frequently do not look upon these newcomers as good risks and question the probable period of residence of the applicant and the strength of local housing demand after completion of the project.

Even when demand appears adequate to insure increased housing production, a number of other factors may constrain the supply of needed housing units. These include:

- UNAVAILABILITY OF MORTAGE CREDIT – Small local economies cannot normally generate the rate of capital formation required to meet the needs for new housing mortgages without importing capital from outside financial centers. The institutional constraints encountered include the absence of effective correspondent banking relationships, the inability to have access to the secondary mortgage market due to the relatively small size of the mortgage packages, and the rejection of secondary mortgage packages as too risky and/or too difficult to evaluate and supervise.

- LIMITATIONS ON LOCAL ENTREPRENEURIAL SKILLS – In some instances, there is no active construction industry prior to initiation of the uranium project.

- UNAVAILABILITY OR HIGH COST OF SKILLED CONSTRUCTION LABOR Whatever local construction force exists may be bid away from the housing industry by the uranium project.

- DIFFICULTIES IN ACQUIRING SUITABLE LAND – This is hampered in coastal areas by environmental constraints and competition from other land users (e.g., resorts), in many semi-rural eastern areas by large lot zoning, in Appalachia by terrain and monopolistic land ownership patterns and in the Rocky Mountains by public land ownership.

- SHORT PAY-OUT PERIODS FOR RENTAL UNITS – Where peak work forces create temporary housing demand, rapid amortization of developers' and creditors' investments may lead to extremely high income requirements for rental units and mobile home sites.

- ABNORMAL FRONT-END RISKS – Where a single project is responsible for a large proportion of the local housing demand (e.g., a large power plant in a small community), developers and construction lenders may feel that their vulnerability to project delays (e.g., due to environmental litigation) is unacceptable. Lenders in particular may refuse to take part in housing developments until project construction is actually underway.
- EXCESSIVE FRONT-END COSTS – Factors limiting land availability may also increase costs of roads, utilities, etc. Also, local governments facing financial difficulties with front-end financing may respond by shifting a portion of the burden to private developers in the form of higher utility tap fees, requirements for cost-sharing on roads and utilities, and requirements for school and park land dedications.

Because of these difficulties and the problems of employee recruitment and retention, housing has become an area where industries have actively intervened. Activities range from (1) attempting to remove the constraints described (i.e., guaranteeing the sale or rental of housing constructed in advance of the project, lease-purchase arrangements for employees, and recruiting outside developers) to (2) acting as developers of bunkhouses, subdivisions and mobile home parks to (3) providing housing subsidies. The extent to which industry becomes involved varies from company to company and from region to region.

5.5.2
Commercial Development

In addition to the housing supply and demand difficulties, the host community can experience other related problems. If there are no effective controls on the pattern of development (i.e., zoning and subdivisions regulations), "rural" sprawl can develop. The difficulties which may be encountered when sprawl development occurs include:

- HEALTH PROBLEMS – Adherence to and enforcement of the health standards associated with water and liquid waste treatment facilities may be neglected.
- INCREASED COST OF PROVIDING PUBLIC SERVICES – Water and sewer lines must be extended to fringe areas, and additional police and fire protection may be difficult to provide.
- SPRAWLED DEVELOPMENT LIKELY TO REMAIN – The pattern of development which first begins in response to the stresses of growth is the one which is likely to continue after growth stabilizes.

Even in the absence of formal controls, communities can exert some degree of authority over growth patterns by carefully choosing when and where to expand utilities and services.

Many of the same financial considerations and constraints can be applied to the problems of commercial development. In small rural areas there is often a lack of local entrepreneurial skill. Furthermore, local lending institutions do not always have the well-developed correspondent banking relationships required to import substantial amounts of outside capital. Outside lenders, as well as local ones, may not be willing to lend money for commercial development when there is substantial uncertainty about the timing and duration of the expected development. Large chain operations (e.g., K–Mart and Safeway) have their own criteria for opening stores in an expected growth area.

Potential actions to enhance opportunities and/or mitigate problems include:

Community actions

- Industrial revenue bonds to improve industrial and commercial sectors' access to credit
- Publicity (e.g., Chamber of Commerce activities) concerning the need for new entrepreneurial activity in local services and housing
- Public housing programs (e.g., HUD Section 12)
- Expanded efforts by local financial institutions to have access to secondary credit markets and develop correspondent banking relationships

Industry actions

- Recruitment of outside housing developers
- Guarantees (underwriting) of credit for housing development started in anticipation of the arrival of construction workers
- Purchase of land for housing development prior to announcement of energy development intentions (to prevent land speculation)
- Acting as housing developers, especially for temporary construction housing

State/federal actions

- Increasing fund allocations and accessibility of FHA mortgage guarantees in impacted areas

For more information see:

Data on housing demand

- Mountain West Research, Inc. Construction Worker Profile. Washington, D.C.: Old West Regional Commission, 1976.
- Wyoming Department of Economic Planning and Development, ongoing housing-market projections.

Examples of previous industry involvement in housing

- Rocky Mountain Energy Company underwrote the construction of 32 homes in a new subdivision in Douglas, Wyoming
- Gulf Oil Company plans to develop a plat of land in Grants, New Mexico. Actual construction will be done by independent contractors. At least one-third of the homes must be offered to general public.
- Phillips Petroleum Company anticipates the development of a Planned Unit Development (PUD) in Thoreau, New Mexico, near Grants. Plans include single family lots, multi-family units, trailer spaces, a park, commercial areas, and a KOA-type park for campers and motor homes to serve temporary construction workers.

5.6
Socio-Cultural and Political Changes

Uranium development projects can have significant social, cultural and political effects on the host community. These changes include varying impacts to diverse parties of interest (e.g., federal, state, or local governmental entities, industry and commercial interests, and the general public). Impacts on long-time residents have included loss of political power traditionally dominated by ranching or farming interests and perceived decline in personal safety. Effects on newcomers have included perceived rejection by long-time residents, strong feelings of alienation, and stress reactions by unemployed mates.

Table 5-8 provides an example of some of the "before" and "after" sociocultural changes expected as a consequence of uranium and other resource development in Converse County, Wyoming.

Reproduced from best available copy.

Indicators	Characteristics of Society—1976	Characteristics of Society—1985
Social Structure		
Economy	Total employment—3,150	Total employment—6,600
	Balanced economic base— Agriculture is 39% of basic employment Mining and processing is 35% Retired individuals comprise 32.4% of population	Single industry economic base— Agriculture is now 15% of basic employment Mining and processing is now 73%
Technology	Expanding job opportunities within the county since 1970; gain of population since 1970 vs. a loss of population in the 1960's	Job opportunities will continue to draw new residents, they may also help stem out migration of young people from the area
	Agriculture technology fairly advanced; large power plant and several mines	Advanced mining and processing technology; more specialized; more diversified and sophisticated; improved technical, educational and professional services in the area
Occupational structure	Rancher & blue collar workers roughly equally significant	Blue collar dominated
Polity		
Regulates distribution of power	Rancher dominated counties (the 3 county commissioners are ranchers); county which has traditionally been antiplanning is now establishing and stressing more comprehensive planning mechanisms	Changes in occupational structure, technology, and economy all must be dealt with and will change constituencies; urban centers will be larger & more complex, will require more planning and administration
Adjudicates conflict and claims	Legislature is rural dominated; county government deals with few conflicts, largely between revenues (taxes) and expenditures (service requirements)	New conflicts: newcomer vs. old timer, more urban vs. rural strain; interindustry & environmental conflicts more common; more concern with & need for Federal intervention with more urbanization; unions probably more of issue & possibly a political force
Culture		
Expressive symbolism	Protestant Christian values—United Methodist, Baptist, Episcopal—37.5% of county population are church adherents (the national average is 50%)	?
	Emphasis on independence and self-reliance—80% of the farms (& ranches) are owner-occupied (the national average is 62%); 20% of all the work force is self-employed (the national average is 11%)	More emphasis on political, social, and economic groups
Institutions		
Family	Attitude of permanence—attachment to the area is high; (76% of 1970 residents had lived in county for 5 years or more)	Presence of a large population who view themselves as temporary
	1972 divorce rate—4.26/1,000 population, an increase in the 1970 rate of 3.03/1,000	?
Education	Low dropout rate of 7.2% (the national average is 25%)	Dropout rate may come closer to the national average as the county becomes more industrial
Communities	Two very small service center towns; high proportion of permanent housing	Growth, more diversity in the two service centers, increase in the proportion of temporary housing; possible degradation of services and overcrowding to accompany rapid growth
SUMMARY	Traditionally an agrarian society, recent increase in the number of miners & construction workers; county now dominated by ranchers and employees of the energy industry; includes service and governmental components	More urban, complex society, including new extractive & processing components: county now dominated by the energy industry

SOURCE: NRC, NUREG 0129
January, 1977

Table 5-8
Indicators of Societal Change - Converse County, Wyoming

5.6.1
Socio-Cultural Changes

Often the integration of newcomers and native populations has been a major problem. This problem is particularly difficult during early development stages when the construction work force arrives and the two different cultures confront each other. In later development stages, the construction work force is replaced by the permanent mining and milling work force and their families. These new permanent residents may be different than the old timers, but ideally, a mutual accommodation occurs. Those families that permanently settle in the community (e.g., buying houses, raising children) eventually become a part of the social, political, religious, cultural and civic life of the community.

Newcomers may have different values and life-styles than the existing population. For example, ranchers may not view leisure-time activities in the same way as miners or construction workers. The newcomers may desire baseball and softball fields, bowling alleys, and the use of farm land and open space for hunting and fishing. These desires might be in conflict with the ranchers' common view that land is to be conserved and valued for production of food, livestock and personal hunting. Denominational affiliation and church attendance may also change.

Cultural differences may be particularly important considerations when uranium development takes place near or on Indian lands and where Indians may account for a significant portion of the work force. Many tribes have varying beliefs and customs that play a significant role in future relationships with other employees and with the uranium companies. For example, in some cases, attempts at hiring Indians for an underground mining operation would be futile. Age-old beliefs keep some tribal members from going underground. Because of strong tribal and family ties, many Indians prefer to live on the reservations and commute to work. Cultural differences are very important considerations in any active recruitment program for Indians.

5.6.2
Political and Demographic Changes

One of the more visible changes that is likely to occur in the community will be the redirection of the social and political leadership. Traditionally, rural communities have been dominated by the ranchers or farmers. As more white-collar and blue-collar workers move into the community and become active in local affairs, they often challenge the traditional leadership. They may hold different views concerning energy development of all types, environmental issues or planning and zoning. These differences will slowly be reconciled and eventually community leadership may be held jointly.

Other expected changes include a shift from an older population to a younger one and an increase in the standard of living for many employees. Often rural communities have an older population, with many of the ranchers having retired to town. Because uranium development increases job opportunities, young people are likely to remain instead of moving out after high school graduation. In addition, new miners and mill employees moving into the area are apt to be in their late 20's or early 30's. The retired population may not decrease, but their size relative to the other segments may change drastically. The uranium industry's wages will be significantly higher than other available positions in the community. This will, in effect, drive up the average wage scale and, perhaps, the cost of living. Elderly residents who live on fixed incomes may be adversely affected by higher rents, food prices, taxes, etc.

Additional sources of information on social change include:

- Davidson, Donna. Social Impact Prevention and Human Service Needs in the Energy Impacted Areas of New Mexico: Recommendations to the State Government. Santa Fe: State of New Mexico Health and Social Services Planning Department, 1977.
- Uhlmann, Julie M., et al. A Study of Two Wyoming Communities Undergoing the Initial Effects of Energy Resource Development in the Powder River Basin: Buffalo and Douglas, Wyoming—1975. Laramie: University of Wyoming, 1976.

5.7
Other Potential Conflicts

Other potentially adverse impacts may occur as a result of conflicts between parties of interest and public agencies and regulatory institutions. Many of these conflicts result from increased competition for water, land or labor within the region. Competition for scarce resources often results in the price of the resource being bid up, the supply reduced or both. Industry and commercial developers often compete with the agricultural and ranching sectors of the economy for land and water. This conflict can become further complicated if land for development includes, or is near recreation or environmentally sensitive areas. For example, some recent wilderness area designations have eliminated potential areas of uranium discovery.

The local markets may also be disrupted as the uranium developers hire at high wages and attract labor from local employers. Personal income of new uranium employees is favorably impacted, but many business and local governmental employers are unable to change their wage structures to compete and are without needed help. Unless some hiring restrictions are imposed, some teenagers may also be tempted to quit school and work for the uranium or construction companies.

Another potential area of conflict is regulatory jurisdictions and responsibilities in overseeing uranium developments. For example, there are state and federal regulations regarding tailings disposal. Some states are agreement states (i.e., they have the authority to issue their own uranium mill licenses), but others are not. To the extent that regulatory uncertainty increases the uncertainty of mine or mill development, the difficulty of mitigating each of the categories of impacts described previously is increased. Many of these conflicts have not been formally addressed.

5.8
Contingency Planning and Monitoring Programs

The state of socioeconomic impact assessment is currently undergoing rapid development, and more reliable forecasting techniques will be available in the future. However, for the present, communities and uranium firms can reduce the penalties for inaccurate forecasting by developing contingency plans.

A community may prepare by planning for a range of likely occurrences. Such contingencies could include alternative capital budgets and reservation of some of the legal bonding capacity for unforeseen events. Financial institutions might plan for flexibility in mortgage terms, and housing developers could design mobile home parks which could later be converted to permanent housing. Contingency planning may be desirable in each of four development phases:

- ANNOUNCEMENT PHASE - For example, to direct adverse effects of speculation in land and housing.
- BUILD-UP PHASE - For example, to encourage a corresponding build-up in local business and to time public sector investments.
- OPERATING PHASE - To monitor changes.
- ABANDONMENT PHASE - To prepare for eventual declines in mine/mill employment as, for example, the ore body is depleted.

Much of the uncertainty surrounding socioeconomic impacts can be removed by continuing monitoring programs. Such monitoring programs have only very recently been initiated to check the accuracy of impact projections, track the effectiveness of mitigative programs and provide a sound basis for mid-program corrections. These monitoring programs are not only very useful in providing more data for general forecasting use, but also can guide the specific project in timely implementation of contingent plans. An effective ongoing monitoring program will help bridge the gap between prediction and actual occurrence and thus permit adjustment of mitigative efforts to changing circumstances.

CHAPTER 5

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Glossary

Adit - A horizontal or nearly horizontal passage driven from the surface for the working or unwatering of a mine.

Amendment - A material added to soil to improve its capability for supporting plant growth, particularly for reclamation.

Autogenous Grinding - Grinding ore by tumbling the material in a revolving cylinder without balls or rods. The ore itself acts as the grinding media.

Btu - British thermal unit.

Beneficiation - The dressing or processing of ores for the purpose of regulating the size of a desired product, removing unwanted constituents, or improving the quality, purity or assay grade of a desired product.

Beta Particle - A positively or negatively charged particle having the mass of an electron which is emitted from a nucleus during radioactive decay.

Breeder Reactor - A reactor which generates more fissile material than it consumes.

CANDU - Canadian Natural Uranium Reactor.

CSMRI - Colorado School of Mines Research Institute.

Caving - An unsupported stoping method in which the hanging wall in the stoped-out area is allowed, or sometimes forced, to collapse and close the opening.

Circuit - The path of material through the mill.

Countercurrent Decantation - The clarification of liquor and the densification of tailings by the use of several thickeners in series. The liquor flows in the opposite direction from the solids.

Curie - A unit quantity of radioactive material in which 3.7×10^{10} disintegrations per second occur.

DES - Draft Environmental Statement.

Dose - An amount of radiation absorbed.

Dose Commitment - The total dose that an organism is expected to receive in its lifetime from a given quantity of radioactive material deposited in the body.

Dose Equivalent - The product of absorbed dose in rads and certain modifying factors. It expresses all radiation on a common scale for calculating the effective absorbed dose.

DRI – Denver Research Institute.

Enrichment - The process of increasing the percentage of the fissionable isotope ^{235}U above that contained in natural uranium, usually to 2–4 percent for use as reactor fuel.

Extractant - The active organic reagent which forms an extractable complex with the dissolved uranium.

FRP - Fiber reinforced polyester, a fiberglass construction material.

Face - The solid surface of the unbroken rock at the advancing end of an underground working.

Fertile - Able to be converted to fissionable material.

Fissile Material - Atoms such as ^{235}U or ^{239}Pu that fission upon absorption of a low energy neutron (Keeny et al., 1977).

Fission - The splitting of an atomic nucleus with the release of energy.

Flocculants - Agents that induce or promote flocculation or aggregation of solids.

Forward Costs - The Department of Energy, through the NURE program, provides estimates of reserves and resources for U_3O_8 at various dollar-per-pound forward costs. The estimates are ranked by cost of recovery termed forward cost. Forward costs are operating and capital costs that are not yet incurred at the time the estimate is made. Past expenditures for such items as property acquisition, exploration, mine development, return on investment, or profit are not included.

The forward costs are not production costs or market selling price. Each forward cost category is used as a maximum cutoff although average costs may be less overall for each reserve or resource estimate (Keeny et al., 1977).

Forward operating costs include direct and indirect mining costs, haulage, royalty and milling costs. Forward capital costs include cost estimates for the mill, mine plant construction, additional mine development and equipment (Meehan, 1977).

The market price to stimulate full production of a resource base may be significantly higher than the estimated cost of producing that resource. Many recent contracts in the early 1980's are \$40 to \$65 per lb in year-of-delivery dollars. In part, the price difference is due to low-grade ore and relatively high-price recovery projects. New underground mines operating at greater depths and new surface mines extracting lower grade ore are examples of high cost projects. Recovery from mill tailings and mined-out areas are relatively high cost also.

GPD - Gallons per day.

GPM - Gallons per minute.

Gamma Radiation - Short wavelength electromagnetic radiation emitted when an excited nucleus drops to its ground state.

Half-Life - The amount of time required for one half of the amount of radioactive material present to decay.

Haulageway - The gangway, entry or tunnel through which mine cars are moved.

In Situ - In a natural or original position.

Injection Well - For a solution mining operation, a lined hole placed in the ore body for the purpose of introducing the leaching solution.

Ion Exchange - Reversible exchange of ions contained in a resin for different ions in solution without destruction of the resin.

Ion Exchange Columns - A vessel packed with beads of resin.

KWHR - Kilowatt-hour.

Leaching - Extracting a soluble compound from an ore by selectively dissolving it in a suitable solvent.

Light Water Reactor (LWR) - A nuclear reactor that uses ordinary water as a coolant to transfer heat from the fissioning uranium to a steam turbine and employs slightly enriched uranium as fuel (Keeny, et al., 1977).

LWR Natural Uranium Requirements - The 1000 MW(e) LWR requires about 550 to 625 short tons of U_3O_8 for initial fuel loading and about 200 tons for annual refueling. The U_3O_8 is processed and enriched slightly for fuel rod assemblies which fuel the reactor. (NRC, GESMO, 1976, pg IV F-1.)

Liquor - Liquid.

Lixiviant - Leaching solution.

Low Grade Ore - Ore which has a low content of the metal for which it is mined.

MCF - Thousand cubic feet.

MT/D - Metric tons per day.

MW(e) - Megawatts of electricity.

Monitor Well - For a solution mining operation, a hole strategically located in the ore body, aquifer, etc., for the purpose of detecting escaping leaching solutions.

Muck - Unconsolidated rock.

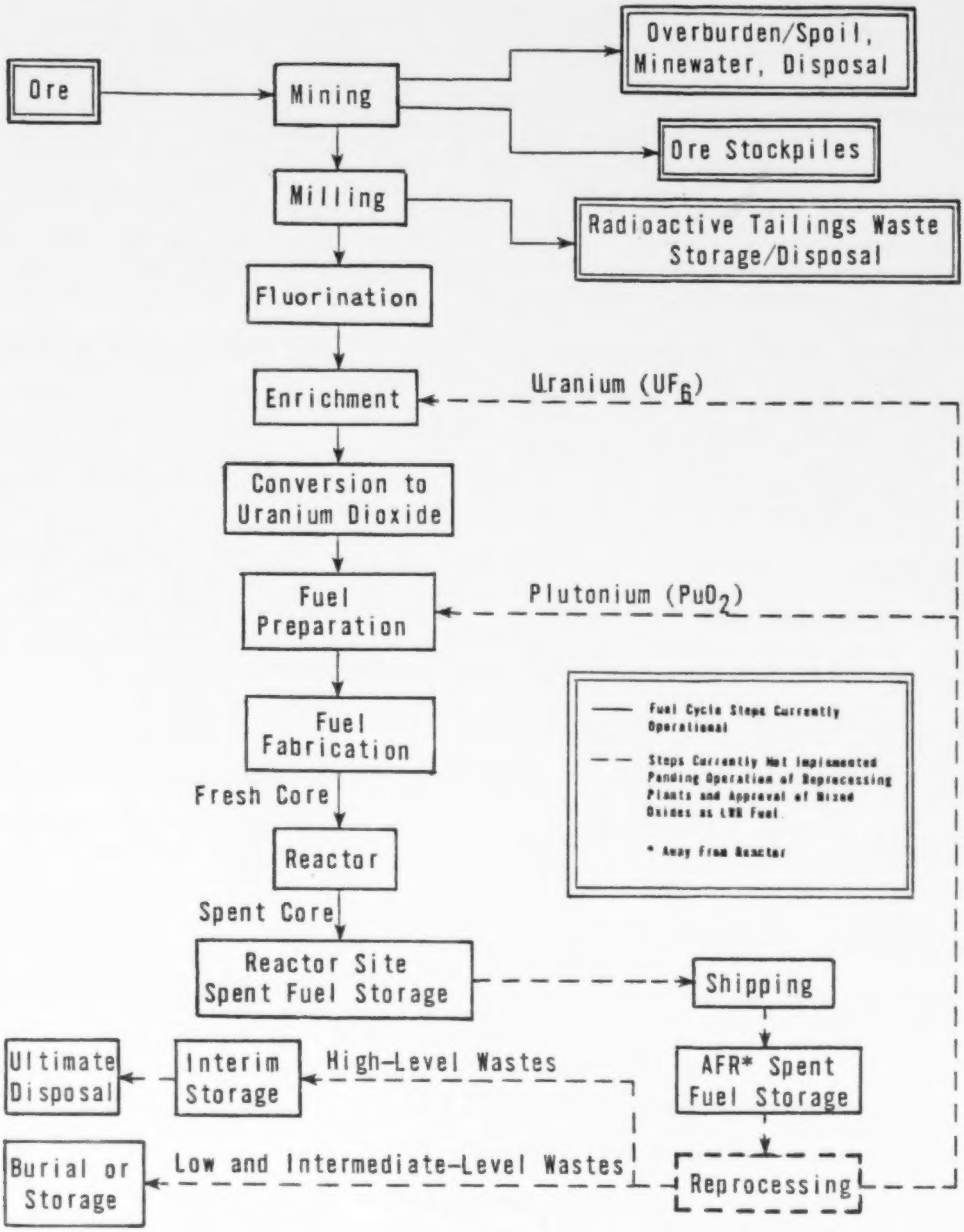
Mudstone Splits - Localized mudstone interbedding between two masses of sandstone.

Nuclear Fuel Cycle - The nuclear fuel cycle for the Light-Water Reactor shown in Figure G-1 depicts the operations that occur before and after fissioning of fuel at the reactor. In the figure the steps connected by a solid line are currently (1978) operational. The steps connected by a dotted line are yet to be implemented pending government resolution of its policy on reprocessing, storage, and disposal of spent fuel.

The nuclear fuel cycle consists of several steps:

- EXTRACTION - removing the ore (uranium) from the ground, separating uranium from the waste, and converting the uranium to a chemically stable oxide (nominally U_3O_8).
- CONVERSION - changing the U_3O_8 to a fluoride (UF_6), which is a solid at room temperature but becomes a gas at slightly elevated temperatures, prior to enrichment.
- ENRICHMENT - concentrating the fissionable isotope (^{235}U) of uranium from the naturally occurring 0.7% to 2-4% for use in reactors for power generation.
- FABRICATION - converting the enriched uranium fluoride to uranium dioxide (UO_2), forming it into pellets, and encasing the pellets in tubes (rods) that are assembled into fuel bundles for use in power generating reactors.
- NUCLEAR POWER GENERATION - using the heat resulting from the fissioning of uranium and plutonium for generating steam for the turbines.
- SPENT FUEL REPROCESSING - chemical separation of fissionable and fertile values (^{235}U, ^{238}U, Pu) from fission products (waste), with concurrent separation of uranium from plutonium.
- WASTE MANAGEMENT - storage of fission products and low-level wastes resulting from reprocessing in a manner that is safe and no threat to health or environment.

Source: NRC, NUREG-0403, 1977.


Ore
Mining
Overburden/Spoil, Minewater, Disposal
Ore Stockpiles
Milling
Radioactive Tailings Waste Storage/Disposal
Fluorination
Enrichment
Uranium (UF_6)
Conversion to Uranium Dioxide
Fuel Preparation
Plutonium (PuO_2)
Fuel Fabrication
Fresh Core
Reactor
Spent Core
Reactor Site Spent Fuel Storage
Shipping
AFR* Spent Fuel Storage
Reprocessing
Ultimate Disposal
Interim Storage
High-Level Wastes
Burial or Storage
Low and Intermediate-Level Wastes
Fuel Cycle Steps Currently Operational
Steps Currently Not Implemented Pending Operation of Reprocessing Plants and Approval of Mixed Oxides as LWR Fuel.
* Away From Reactor

SOURCE: Adapted from NRC, DES, NUREG-0403

Figure G-1
The Light Water Reactor Fuel Cycle

The extraction step also shows the spoil material produced in mining and the tailings residue remaining after milling (conversion of ore to U_3O_8 concentrate). The concentrate is called "yellowcake" and is about 75 percent uranium. The largest portion of the ore (feed for the mill) remaining as tailings is depleted in uranium but contains radium 226 and its long half life parent thorium 230. These tailings are a source of radon 222 emissions, which can last for thousands of years (EPA, Technical Note, 1976). The storage and disposal of these radioactive materials and the radiological concern about them are discussed in detail in Chapter 4.

The NRC, Draft Environmental Statement related to the operation of Sweetwater Uranium Project, pages H-1, H-2, NUREG-0403, NRC December 1977 provides additional details on the nuclear fuel cycle. Also the reader is referred to Ellett, W.H.M. and Richardson, A.C.B., Estimates of the Cancer Risk Due to Nuclear-Electric Power Generation, 35pp, Environmental Protection Agency, Technical Note ORP/CSD-76-2, EPA, October 1976.

Ore Body - Generally, a solid and fairly continuous mass of ore, which may include low-grade ore and waste as well as pay ore, but is individualized by form or character from adjoining country rock (Fay, b.s. Afr.). A mineral deposit that can be worked at a profit under the existing economic conditions.

PPM - Parts per million parts.

PVC - Polyvinyl chloride, a plastic construction material.

Pathway - Any specific process or combination of processes whereby a material is transported from its source to a destination.

Pedogenic - Relating to the soil.

Phreatic Surface - The elevation at which the pressure in the water is zero with respect to the atmosphere.

Porosity - The ratio of the volume of interstices in a material to the volume of material.

Portal - Any entrance to a mine.

Pulp - A mixture of solids and leaching solution.

Rad - A dose of ionizing radiation equal to 0.01 joules per kilogram of irradiated material.

Rainout - In-cloud scavenging of aerosol particles by ice crystals.

Recovery Well - For a solution mining operation, a lined hole placed in the ore body for the purpose of removing the leaching solution which contains dissolved uranium.

Refractory Ore - Ore which is difficult to treat for recovery of the valuable substances.

Rem - (Roentgen Equivalent Man) A special unit of dose equivalent, in rems, numerically equal to the absorbed dose, in rads, multiplied by modifying factors.

Roentgen - The special unit of exposure. One roentgen equals 2.58 x 10^4 coulomb per kilogram of air.

Reprocessing - The process of recovery of uranium and plutonium from spent fuel.

Reserves - For uranium those resources that are known in location, quantity and quality and that are recoverable below a specified cost using currently available technologies (Keeny, et al., 1977).

Resources - Deposits that may be known to exist, but not in such quantity or state as to be economically recoverable by present technologies, or those that are unidentified but suspected or probable on the basis of indirect evidence (Keeny, et al, 1977).

"Probable" Potential Resources - Those estimated to occur in known productive uranium districts:

1. In extensions of known deposits, or
2. In undiscovered deposits within known geologic trends or areas of mineralization.

"Possible" Potential Resources - Those estimated to occur in undiscovered or partly defined deposits in formation or geologic settings productive elsewhere within the same geologic province.

"Speculative" Potential Resources - Those estimated to occur in undiscovered or partly defined deposits:

1. In formations or geologic settings not previously productive within a productive geologic province, or
2. Within a geologic province not previously productive.

"Productive" infers that past production plus known reserves exceed 10 tons U_3O_8.

Saltation - The process of soil transport where a wind-blown soil particle impacts the ground and dislodges other soil particles.

Semi-Autogenous Grinding - Grinding ore by tumbling the material in a revolving cylinder with fewer steel balls or rods than in typical ball or rod mills.

Separative Work - Work required to separate isotopes in the enrichment process, measured in Separative Work Units (SWU's). It takes about 100,000 SWU's per year to keep a 1000 MW(e) LWR operating.

Shaft - A vertical or inclined excavation of limited area compared with its depth, made for finding ore, mining ore, raising water, ore, rock, hoisting or lowering men and material or ventilating underground workings.

Skip - A guided hopper, usually rectangular, used in vertical or inclined shafts for hoisting rock, men or materials.

Solution Mining - The technique of dissolving minerals in situ by injecting a suitable leaching solution into the ore body and recovering the metal bearing liquors in a pattern of wells.

Solvent Extraction - Selective transfer of metal salts from aqueous solutions to an immiscible organic liquid.

Somatic - An adjective pertaining to the body.

Source Term - The quantity of material which is released from a given source per unit time. The source term may include a qualitative description of the material released, as well as the geometry of the release.

Sparging - In this context, bubbling gas into liquid or a liquid-solid mixture.

Spent Fuel - The fuel removed from a reactor after several years of generating power. Spent fuel contains radioactive waste materials, unburned uranium and plutonium (Keeny et al., 1977).

Stope - An underground opening from which ore is being excavated in a series of steps.

Stoping - The act of excavating ore by means of a series of horizontal, vertical or inclined workings in veins or large, irregular bodies of ore, or by rooms in a flat deposit. Includes the breaking and removal of ore from underground openings, except those driven for exploration and development.

Stripping Ratio - The unit amount of waste that must be removed to gain access to a similar unit amount of ore.

Student "t" Test - A common statistical procedure used to test the difference between the means of two sets of numbers.

Sump - That portion of the shaft below the normal winding level which is used for the collection of water for pumping.

Surface Mining - Mining in surface excavations.

SWEC - Stone & Webster Engineering Corporation.

TPD - Tons per day.

Tails Assay - The percentage of the isotope ^{235}U in the uranium remaining after production of enriched uranium. The percentage is usually less than 0.3 percent.

Tunnel - A horizontal or nearly horizontal underground passage that is open to the atmosphere at both ends.

Uraniferous - Uranium bearing.

Uranium Oxide (U_3O_8) - The most common oxide of uranium in ore. The amount of elemental uranium in raw material (in terms of black oxide equivalent, U_3O_8) may be determined by multiplying the U_3O_8 content by 0.85.

Vat Leaching - Leaching in troughs without mechanical agitation.

Washout - Scavenging of aerosol particles by falling raindrops or ice crystals.

Well Field - For a solution mining operation, the area which encompasses the injection and recovery wells.

Yellowcake - The uranium concentrate produced by uranium mills.